

STUDY GUIDE  
AND  
SOLUTIONS MANUAL  
TO ACCOMPANY  
**ORGANIC  
CHEMISTRY**  
SEVENTH EDITION

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you fill with your own writing in studying during the term.

5. **Learn by teaching and explaining.** Study with your student peers and practice explaining concepts and mechanisms to each other. Use the *Learning Group Problems* and other exercises your instructor may assign as vehicles for teaching and learning interactively with your peers.
6. **Use the answers to the problems in the *Study Guide* in the proper way.** Refer to the answers only in two circumstances: (1) When you have finished a problem, use the Study Guide to check your answer. (2) When, after making a real effort to solve the problem, you find that you are completely stuck, then look at the answer for a clue and go back to work out the problem on your own. The value of a problem is in solving it. If you simply read the problem and look up the answer, you will deprive yourself of an important way to learn.
7. **Use the introductory material in the *Study Guide* entitled "Solving the Puzzle—or—Structure Is Everything (Almost)" as a bridge**

from general chemistry to your beginning study of organic chemistry. You might find this section helpful as a way to see the relevance to organic chemistry of some of the concepts you learned in general chemistry, while at the same time refreshing these ideas in your mind and gearing you up to study organic chemistry. It is also meant to help you see that an understanding of certain fundamental principles, largely having to do with structure, can help immensely to reduce the complexity of the puzzle you may feel lies ahead of you. Indeed, once you have a firm understanding of structure, the puzzle of organic chemistry can become one of very manageable size and comprehensible pieces.

8. **Use molecular models when you study.** Because of the three-dimensional nature of most organic molecules, molecular models can be an invaluable aid to your understanding of them. Buy yourself an inexpensive molecular model set and use it when you need to see the three-dimensional aspect of the particular topic. An appendix in the *Study Guide* provides a set of highly useful molecular model exercises.

## INTRODUCTION

### "Solving the Puzzle"

or

### "Structure Is Everything (Almost)"

As you begin your study of organic chemistry it may seem like a puzzling subject. In fact, in many ways organic chemistry is like a puzzle—a jigsaw puzzle. But it is a jigsaw puzzle with useful pieces, and a puzzle with fewer pieces than perhaps you first thought. In order to put a jigsaw puzzle together you must consider the shape of the pieces and how one piece fits together with another. In other words, solving a jigsaw puzzle is about **structure**. In organic chemistry, molecules are the pieces of the puzzle. Much of organic chemistry, indeed life itself, depends upon the fit of one molecular puzzle piece with another. For example, when an antibody of our immune system acts upon a foreign substance, it is the puzzle-piece-like fit of the antibody with the invading molecule that allows "capture" of the foreign substance. When we smell the sweet scent of a rose, some of the neural impulses are initiated by the fit of a molecule called geraniol in an olfactory receptor site in our nose. When an adhesive binds two surfaces together, it does so by billions of interactions between the molecules of the two materials. Chemistry is truly a captivating subject.

As you make the transition from your study of general to organic chemistry, it is important that you solidify those concepts that will help you understand the structure of organic molecules. A number of concepts are discussed below using several examples. It is suggested that you consider the examples and the explanations given, and refer to information from your general chemistry studies when you need more elaborate information. There are also occasional references below to sections in your text, Solomons's and Fryhle's *Organic Chemistry*, because some of what follows foreshadows what you will learn in the course.

## SOME FUNDAMENTAL PRINCIPLES WE NEED TO CONSIDER

What do we need to know to understand the structure of organic molecules? First, we need to know where electrons are located around a given atom. To understand this we need to recall from general chemistry the ideas of **electron configuration** and **valence shell electron orbitals**, especially in the case of atoms such as carbon, hydrogen, oxygen, and nitrogen. We also need to use **Lewis valence shell electron structures**. These concepts are useful because the shape of a molecule is defined by its constituent atoms, and the placement of the atoms follows from the location of the electrons that bond the atoms. Once we have a Lewis structure for a molecule, we can consider **orbital hybridization** and **valence shell electron pair repulsion (VSEPR) theory** in order to generate a three-dimensional image of the molecule.

Secondly, in order to understand why specific organic molecular puzzle pieces fit together we need to consider the attractive and repulsive forces between them. To understand this we need to know how electronic charge is distributed in a molecule. We must



use tools such as **formal charge** and **electronegativity**. That is, we need to know which parts of a molecule are relatively positive and which are relatively negative—in other words, their **polarity**. Associations between molecules strongly depend on both shape and the complementarity of their electrostatic charges (polarity).

When it comes to organic chemistry it will be much easier for you to understand why organic molecules have certain properties and react the way they do if you have an appreciation for the structure of the molecules involved. Structure is, in fact, almost everything, in that whenever we want to know why or how something works we look ever more deeply into its structure. This is true whether we are considering a toaster, jet engine, or an organic reaction. If you can visualize the shape of the puzzle pieces in organic chemistry (molecules), you will see more easily how they fit together (react).

### SOME EXAMPLES

In order to review some of the concepts that will help us understand the structure of organic molecules, let's consider three very important molecules—water, methane, and methanol (methyl alcohol). These three are small and relatively simple molecules that have certain similarities among them, yet distinct differences that can be understood on the basis of their structures. Water is a liquid with a moderately high boiling point that does not dissolve organic compounds well. Methanol is also a liquid, with a lower boiling point than water, but one that dissolves many organic compounds easily. Methane is a gas, having a boiling point well below room temperature. Water and methanol will dissolve in each other, that is, they are miscible. We shall study the structures of water, methanol, and methane because the principles we learn with these compounds can be extended to much larger molecules.

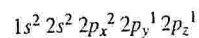
#### Water

#### HOH

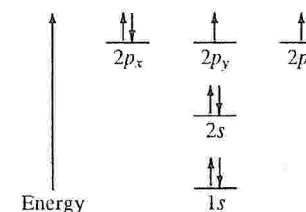
Let's consider the structure of water, beginning with the central oxygen atom. Recall that the atomic number (the number of protons) for oxygen is eight. Therefore, an oxygen atom also has eight electrons. (An ion may have more or less electrons than the atomic number for the element, depending on the charge of the ion.) Only the valence (outermost) shell electrons are involved in bonding. Oxygen has six valence electrons—that is, six electrons in the second principal shell. (Recall that the number of valence electrons is apparent from the group number of the element in the periodic table, and the row number for the element is the principal shell number for its valence electrons.) Now, let's consider the electron configuration for oxygen. The sequence of atomic orbitals for the first three shells of any atom is shown below. Oxygen uses only the first two shells in its lowest energy state.

$1s, 2s, 2p_x, 2p_y, 2p_z, 3s, 3p_x, 3p_y, 3p_z$

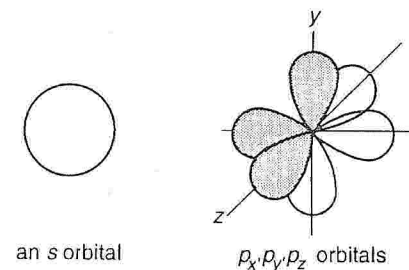
The  $p$  orbitals of any given principal shell (second, third, etc.) are of equal energy. Recall also that each orbital can hold a maximum of two electrons and that each orbital must accept one electron before a second can reside there (Hund's rule). So, for oxygen we place two electrons in the  $1s$  orbital, two in the  $2s$  orbital, and one in each of the  $2p$  orbitals, for a subtotal of seven electrons. The final eighth electron is paired with another in one of the  $2p$  orbitals. The configuration for the eight electrons of oxygen is, therefore



where the superscript numbers indicate how many electrons are in each orbital. In terms of relative energy of these orbitals, the following diagram can be drawn. Note that the three  $2p$  orbitals are depicted at the same relative energy level.



Now, let's consider the shape of these orbitals. The shape of an  $s$  orbital is that of a sphere with the nucleus at the center. The shape of each  $p$  orbital is approximately that of a dumbbell or lobe-shaped object, with the nucleus directly between the two lobes. There is one pair of lobes for each of the three  $p$  orbitals ( $p_x, p_y, p_z$ ), and they are aligned along the  $x, y$ , and  $z$  coordinate axes, with the nucleus at the origin. Note that this implies that the three  $p$  orbitals are at  $90^\circ$  angles to each other.



Now, when oxygen is bonded to two hydrogens, bonding is accomplished by the sharing of an electron from each of the hydrogens with an unpaired electron from the oxygen. This type of bond, involving the sharing of electrons between atoms, is called a **covalent bond**. The formation of covalent bonds between the oxygen atom and the two hydrogen atoms is advantageous because each atom achieves a full valence shell by the sharing of these electrons. For the oxygen in a water molecule, this amounts to satisfying the octet rule.

A **Lewis structure** for the water molecule (which shows only the valence shell electrons) is depicted in the following structure. There are two nonbonding pairs of electrons around the oxygen as well as two bonding pairs.



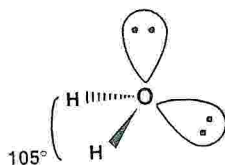
In the left-hand structure the six valence electrons contributed by the oxygen are shown as dots, while those from the hydrogens are shown as  $x$ 's. This is done strictly for bookkeeping

purposes. All electrons are, of course, identical. The right-hand structure uses the convention that a bonding pair of electrons can be shown by a single line between the bonded atoms.

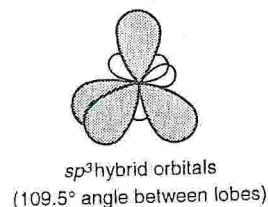
This structural model for water is only a *first approximation*, however. While it is a proper Lewis structure for water, it is not an entirely correct three-dimensional structure. It might appear that the angle between the hydrogen atoms (or between any two pairs of electrons in a water molecule) would be  $90^\circ$ , but this is not what the true angles are in a water molecule. The angle between the two hydrogens is in fact about  $105^\circ$ , and the nonbonding electron pairs are in a different plane than the hydrogen atoms. The reason for this arrangement is that groups of bonding and nonbonding electrons tend to repel each other due to the negative charge of the electrons. Thus, the ideal angles between bonding and nonbonding groups of electrons are those angles that allow maximum separation in three-dimensional space. This principle and the theory built around it are called the **valence shell electron pair repulsion (VSEPR) theory**.

VSEPR theory predicts that the ideal separation between four groups of electrons around an atom is  $109.5^\circ$ , the so-called **tetrahedral angle**. At an angle of  $109.5^\circ$  all four electron groups are separated equally from each other, being oriented toward the corners of a regular tetrahedron. The exact tetrahedral angle of  $109.5^\circ$  is found in structures where the four groups of electrons and bonded groups are identical.

In water, there are two different types of electron groups—pairs bonding the hydrogens with the oxygen and nonbonding pairs. Nonbonding electron pairs repel each other with greater force than bonding pairs, so the separation between them is greater. Consequently, the angle between the pairs bonding the hydrogens to the oxygen in a water molecule is compressed slightly from  $109.5^\circ$ , being actually about  $105^\circ$ . As we shall see shortly, the angle between the four groups of bonding electrons in methane ( $\text{CH}_4$ ) is the ideal tetrahedral angle of  $109.5^\circ$ . This is because the four groups of electrons and bound atoms are identical in a methane molecule.



**Orbital hybridization** is the reason that  $109.5^\circ$  is the ideal tetrahedral angle. As noted earlier, an  $s$  orbital is spherical, and each  $p$  orbital is shaped like two symmetrical lobes aligned along the  $x$ ,  $y$ , and  $z$  coordinate axes. Orbital hybridization involves taking a weighted average of the valence electron orbitals of the atom, resulting in the same number of new hybridized orbitals. With four groups of valence electrons, as in the structure of water, one  $s$  orbital and three  $p$  orbitals from the second principal shell in oxygen are hybridized (the  $2s$  and  $2p_x$ ,  $2p_y$ , and  $2p_z$  orbitals). The result is four new hybrid orbitals of equal energy designated as  $sp^3$  orbitals (instead of the original three  $p$  orbitals and one  $s$  orbital). Each of the four  $sp^3$  orbitals has roughly 25%  $s$  character and 75%  $p$  character. The geometric result is that the major lobes of the four  $sp^3$  orbitals are oriented toward the corners of a tetrahedron with an angle of  $109.5^\circ$  between them.



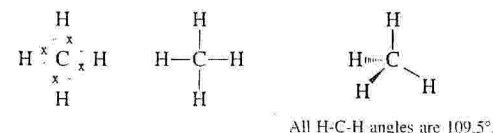
In the case of the oxygen in a water molecule, where two of the four  $sp^3$  orbitals are occupied by nonbonding pairs, the angle of separation between them is larger than  $109.5^\circ$  due to additional electrostatic repulsion of the nonbonding pairs. Consequently, the angle between the bonding electrons is slightly smaller, about  $105^\circ$ .

More detail about orbital hybridization than provided above is given in Sections 1.10–1.14 of *Organic Chemistry*. With that greater detail it will be apparent from consideration of orbital hybridization that for three groups of valence electrons the ideal separation is  $120^\circ$  (trigonal planar), and for two groups of valence electrons the ideal separation is  $180^\circ$  (linear). VSEPR theory allows us to come to essentially the same conclusion as by the mathematical hybridization of orbitals, and it will serve us for the moment in predicting the three-dimensional shape of molecules.

### Methane

#### $\text{CH}_4$

Now let's consider the structure of methane ( $\text{CH}_4$ ). In methane there is a central carbon atom bearing four bonded hydrogens. Carbon has six electrons in total, with four of them being valence electrons. (Carbon is in Group 4 in the periodic table.) In methane each valence electron is shared with an electron from a hydrogen atom to form four covalent bonds. This information allows us to draw a Lewis structure for methane (see below). With four groups of valence electrons the VSEPR theory allows us to predict that the three-dimensional shape of a methane molecule should be tetrahedral, with an angle of  $109.5^\circ$  between each of the bonded hydrogens. This is indeed the case. Orbital hybridization arguments can also be used to show that there are four equivalent  $sp^3$  hybrid orbitals around the carbon atom, separated by an angle of  $109.5^\circ$ .



The structure at the far right above uses the dash-wedge notation to indicate three dimensions. A solid wedge indicates that a bond projects out of the paper toward the reader. A dashed bond indicates that it projects behind the paper away from the viewer. Ordinary lines represent bonds in the plane of the paper. The dash-wedge notation is an important and widely used tool for depicting the three-dimensional structure of molecules.

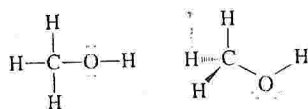
### Methanol

#### $\text{CH}_3\text{OH}$

Now let's consider a molecule that incorporates structural aspects of both water and methane. Methanol ( $\text{CH}_3\text{OH}$ ), or methyl alcohol, is such a molecule. In methanol, a central carbon atom has three hydrogens and an O–H group bonded to it. Three of the four valence electrons of the carbon atom are shared with a valence electron from the hydrogen atoms, forming three C–H bonds. The fourth valence electron of the carbon is shared with a valence electron from the oxygen atom, forming a C–O bond. The carbon atom now has an octet of valence electrons through the formation of four covalent bonds. The angles between these four covalent bonds is very near the ideal tetrahedral angle of  $109.5^\circ$ , allowing maximum separation between them. (The valence orbitals of the carbon are  $sp^3$  hybridized.) At the oxygen atom, the situation is very similar to that in water. The oxygen uses its two unpaired valence electrons to form covalent bonds. One valence electron is used in the bond with the carbon atom, and the other is paired with an electron from the hydrogen to form the O–H



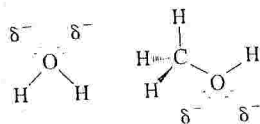
bond. The remaining valence electrons of the oxygen are present as two nonbonding pairs, just as in water. The angles separating the four groups of electrons around the oxygen are thus near the ideal angle of  $109.5^\circ$ , but reduced slightly in the C–O–H angle due to repulsion by the two nonbonding pairs on the oxygen. (The valence orbitals of the oxygen are also  $sp^3$  hybridized since there are four groups of valence electrons.) A Lewis structure for methanol is shown below, along with a three-dimensional perspective drawing.



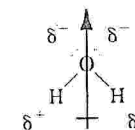
### THE "CHARACTER" OF THE PUZZLE PIECES

With a mental image of the three-dimensional structures of water, methane, and methanol, we can ask how the structure of each, as a "puzzle piece," influences the interaction of each molecule with identical and different molecules. In order to answer this question we have to move one step beyond the three-dimensional shape of these molecules. We need to consider not only the location of the electron groups (bonding and nonbonding) but also the distribution of electronic charge in the molecules.

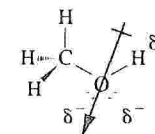
First, we note that nonbonding electrons represent a locus of negative charge, more so than electrons involved in bonding. Thus, water would be expected to have some partial negative charge localized in the region of the nonbonding electron pairs of the oxygen. The same would be true for a methanol molecule.



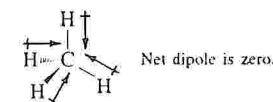
Secondly, the phenomenon of electronegativity influences the distribution of electrons, and hence the charge in a molecule, especially with respect to electrons in covalent bonds. **Electronegativity** is the propensity of an element to draw electrons toward it in a covalent bond. The trend among elements is that of increasing electronegativity toward the upper right corner of the periodic table. (Fluorine is the most electronegative element.) By observing the relative locations of carbon, oxygen, and hydrogen in the periodic table, we can see that oxygen is the most electronegative of these three elements. Carbon is more electronegative than hydrogen, although only slightly. Oxygen is significantly more electronegative than hydrogen. Thus, there is substantial separation of charge in a water molecule, due not only to the nonbonding electron pairs on the oxygen but also to the greater electronegativity of the oxygen with respect to the hydrogens. The oxygen tends to draw electron density toward itself in the bonds with the hydrogens, leaving the hydrogens partially positive. The resulting separation of charge is called **polarity**. The oxygen–hydrogen bonds are called **polar covalent bonds** due to this separation of charge. If one considers the net effect of the two nonbonding electron pairs in a water molecule as being a region of negative charge, and the hydrogens as being a region of relative positive charge, it is clear that a water molecule has substantial separation of charge, or polarity.



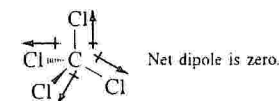
An analysis of polarity for a methanol molecule would proceed similarly to that for water. Methanol, however, is less polar than water because only one O–H bond is present. Nevertheless, the region of the molecule around the two nonbonding electron pairs of the oxygen is relatively negative, and the region near the hydrogen is relatively positive. The electronegativity difference between the oxygen and the carbon is not as large as that between oxygen and hydrogen, however, so there is less polarity associated with the C–O bond. Since there is even less difference in electronegativity between hydrogen and carbon in the three C–H bonds, these bonds contribute essentially no polarity to the molecule. The net effect for methanol is to make it a polar molecule, but less so than water due to the nonpolar character of the CH<sub>3</sub> region of the molecule.



Now let's consider methane. Methane is a nonpolar molecule. This is evident first because there are no nonbonding electron pairs, and secondly because there is relatively little electronegativity difference between the hydrogens and the central carbon. Furthermore, what little electronegativity difference there is between the hydrogens and the central carbon atom is negated by the symmetrical distribution of the C–H bonds in the tetrahedral shape of methane. The slight polarity of each C–H bond is canceled by the symmetrical orientation of the four C–H bonds. If considered as vectors, the vector sum of the four slightly polar covalent bonds oriented at  $109.5^\circ$  to each other would be zero.



The same analysis would hold true for a molecule with identical bonded groups, but groups having electronegativity significantly different from carbon, so long as there were symmetrical distribution of the bonded groups. Tetrachloromethane (carbon tetrachloride) is such a molecule. It has no net polarity.



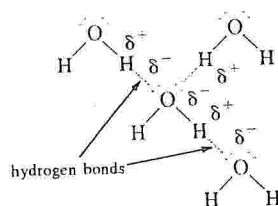


## INTERACTIONS OF THE PUZZLE PIECES

Now that you have an appreciation for the polarity and shape of these molecules it is possible to see how molecules might interact with each other. The presence of polarity in a molecule bestows upon it attractive or repulsive forces in relation to other molecules. The negative part of one molecule is attracted to the positive region of another. Conversely, if there is little polarity in a molecule, the attractive forces it can exert are very small [though not completely nonexistent, due to van der Waals forces (Section 2.14D in *Organic Chemistry*)]. Such effects are called **intermolecular forces** (forces between molecules), and strongly depend on the polarity of a molecule or certain bonds within it (especially O–H, N–H, and other bonds between hydrogen and more electronegative atoms with nonbonding pairs). Intermolecular forces have profound effects on physical properties such as **boiling point**, **solubility**, and **reactivity**. An important manifestation of these properties is that the ability to isolate a pure compound after a reaction often depends on differences in boiling point, solubility, and sometimes reactivity among the compounds present.

### Boiling Point

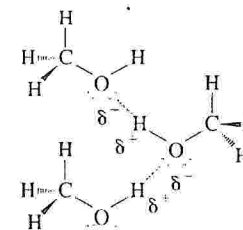
An intuitive understanding of boiling points will serve you well when working in the laboratory. The polarity of water molecules leads to relatively strong intermolecular attraction between water molecules. One result is the moderately high boiling point of water (100°C, as compared to 65°C for methanol and –162°C for methane, which we will discuss shortly). Water has the highest boiling point of these three example molecules because it will strongly associate with itself by attraction of the partially positive hydrogens of one molecule (from the electronegativity difference between the O and H) to the negatively charged region in another water molecule (where the nonbonding pairs are located).



The specific attraction between a partially positive hydrogen atom attached to a heteroatom (an atom with both nonbonding and bonding valence electrons, e.g., oxygen or nitrogen) and the nonbonding electrons of another heteroatom is called **hydrogen bonding**. It is a form of **dipole-dipole attraction** due to the polar nature of the hydrogen-heteroatom bond. A given water molecule can associate by hydrogen bonding with several other water molecules, as shown above. Each water molecule has two hydrogens that can associate with the nonbonding pairs of other water molecules, and two nonbonding pairs that can associate with the hydrogens of other water molecules. Thus, several hydrogen bonds are possible for each water molecule. It takes a significant amount of energy (provided by heat, for example) to give the molecules enough kinetic energy (motion) for them to overcome the polarity-induced attractive forces between them and escape into the vapor phase (evaporation or boiling).

Methanol, on the other hand, has a lower boiling point than water (65°C), in large part due to the decreased hydrogen bonding ability of methanol in comparison with water. Each methanol molecule has only one hydrogen atom that can participate in a hydrogen bond with the nonbonding electron pairs of another methanol molecule (as compared with

two for each water molecule). The result is reduced intermolecular attraction between methanol molecules and a lower boiling point since less energy is required to overcome the lesser intermolecular attractive forces.



The CH<sub>3</sub> group of methanol does not participate in dipole-dipole attractions between molecules because there is not sufficient polarity in any of its bonds to lead to significant partial positive or negative charges. This is due to the small electronegativity difference between the carbon and hydrogen in each of the C–H bonds.

Now, on to methane. Methane has no hydrogens that are eligible for hydrogen bonding, since none is attached to a heteroatom such as oxygen. Due to the small difference in electronegativity between carbon and hydrogen there are no bonds with any significant polarity. Furthermore, what slight polarity there is in each C–H bond is canceled due to the tetrahedral symmetry of the molecule. [The minute attraction that is present between methane molecules is due to van der Waals forces, but these are negligible in comparison to dipole-dipole interactions that exist when significant differences in electronegativity are present in molecules such as water and methanol.] Thus, because there is only a very weak attractive force between methane molecules, the boiling point of methane is very low (–162°C) and it is a gas at ambient temperature and pressure.



### Solubility

An appreciation for trends in solubility is very useful in gaining a general understanding of many practical aspects of chemistry. The ability of molecules to dissolve other molecules or solutes is strongly affected by polarity. The polarity of water is frequently exploited during the isolation of an organic reaction product because water will not dissolve most organic compounds but will dissolve salts, many inorganic materials, and other polar byproducts that may be present in a reaction mixture.

As to our example molecules, water and methanol are miscible with each other because each is polar and can interact with the other by dipole-dipole hydrogen bonding interactions. Since methane is a gas under ordinary conditions, for the purposes of this discussion let's consider a close relative of methane – hexane. Hexane (C<sub>6</sub>H<sub>14</sub>) is a liquid having only carbon – carbon and carbon – hydrogen bonds. It belongs to the same chemical family as methane. Hexane is *not* soluble in water due to the essential absence of polarity in its bonds. Hexane is slightly soluble in methanol due to the compatibility of the nonpolar CH<sub>3</sub> region of methanol with hexane. The old saying “like dissolves like” definitely holds true. This can be extended to solutes, as well. Very polar substances, such as ionic compounds, are usually freely soluble in water. The high polarity of salts generally prevents

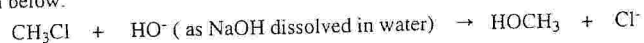
most of them from being soluble in methanol, however. And, of course, there is absolutely no solubility of ionic substances in hexane. On the other hand, very nonpolar substances, such as oils, would be soluble in hexane.

Thus, the structure of each of these molecules we've used for examples (water, methanol, and methane) has a profound effect on their respective physical properties. The presence of nonbonding electron pairs and polar covalent bonds in water and methanol versus the complete absence of these features in the structure of methane imparts markedly different physical properties to these three compounds. Water, a small molecule with strong intermolecular forces, is a moderately high boiling liquid. Methane, a small molecule with only very weak intermolecular forces, is a gas. Methanol, a molecule combining structural aspects of both water and methane, is a relatively low boiling liquid, having sufficient intermolecular forces to keep the molecules associated as a liquid, but not so strong that mild heat can't disrupt their association.

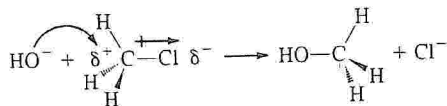
### Reactivity

While the practical importance of the physical properties of organic compounds may only be starting to become apparent, one strong influence of polarity is on the **reactivity** of molecules. It is often possible to understand the basis for a given reaction in organic chemistry by considering the relative polarity of molecules and the propensity, or lack thereof, for them to interact with each other.

Let us consider one example of reactivity that can be understood at the initial level by considering structure and polarity. When chloromethane ( $\text{CH}_3\text{Cl}$ ) is exposed to hydroxide ions ( $\text{OH}^-$ ) in water a reaction occurs that produces methanol. This reaction is shown below.



This reaction is called a substitution reaction, and it is of a general type that you will spend considerable time studying in organic chemistry. The reason this reaction occurs readily can be understood by considering the principles of structure and polarity that we have been discussing. The hydroxide ion has a negative charge associated with it, and thus should be attracted to a species that has positive charge. Now recall our discussion of electronegativity and polar covalent bonds, and apply these ideas to the structure of chloromethane. The chlorine atom is significantly more electronegative than carbon (note its position in the periodic table). Thus, the covalent bond between the carbon and the chlorine is polarized such that there is partial negative charge on the chlorine and partial positive charge on the carbon. This provides the positive site that attracts the hydroxide anion!



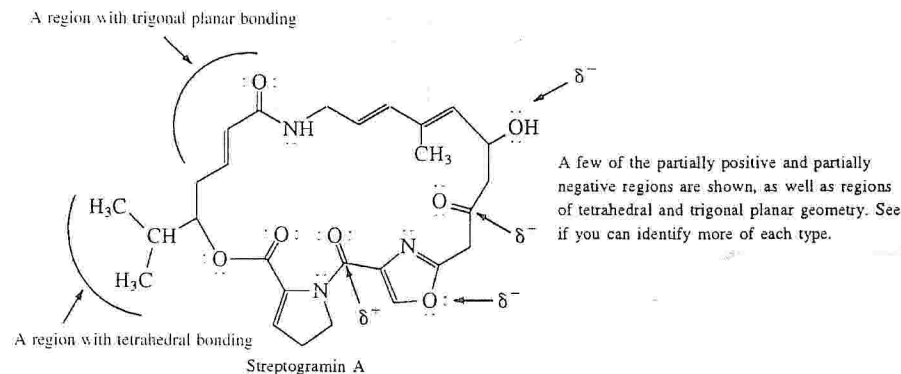
The intimate details of this reaction will be studied in Chapter 6 of your text. Suffice it to say for the moment that the hydroxide ion attacks the carbon atom using one of its nonbonding electron pairs to form a bond with the carbon. At the same time, the chlorine atom is pushed away from the carbon and takes with it the pair of electrons that used to bond it to the carbon. The result is substitution of OH for Cl at the carbon atom and the synthesis of methanol. By calculating **formal charges** (Section 1.7 in the text) one can show that the oxygen of the hydroxide anion goes from having a formal negative charge in hydroxide to zero formal charge in the methanol molecule. Similarly, the chlorine atom goes from having

zero formal charge in chloromethane to a formal negative charge as a chloride ion after the reaction. *The fact that the reaction takes place at all rests largely upon the complementary polarity of the interacting species. This is a pervasive theme in organic chemistry.*

**Acid-base reactions** are also very important in organic chemistry. Many organic reactions involve at least one step in the overall process that is fundamentally an acid-base reaction. Both Bronsted-Lowry acid-base reactions (those involving proton donors and acceptors) and Lewis acid-base reactions (those involving electron pair acceptors and donors, respectively) are important. In fact, the reaction above can be classified as a Lewis acid-base reaction in that the hydroxide ion acts as a Lewis base to attack the partially positive carbon as a Lewis acid. It is strongly recommended that you review concepts you have learned previously regarding acid-base reactions. Chapter 3 in *Organic Chemistry* will help in this regard, but it is advisable that you begin some early review about acids and bases based on your previous studies. Acid-base chemistry is widely applicable to understanding organic reactions.

### JOINING THE PIECES

Finally, while what we have said above has largely been in reference to three specific compounds, water, methanol, and methane, the principles involved find exceptionally broad application in understanding the structure, and hence reactivity, of organic molecules in general. You will find it constantly useful in your study of organic chemistry to consider the electronic structure of the molecules with which you are presented, the shape caused by the distribution of electrons in a molecule, the ensuing polarity, and the resulting potential for that molecule's reactivity. What we have said about these very small molecules of water, methanol, and methane can be extended to consideration of molecules with 10 to 100 times as many atoms. You would simply apply these principles to small sections of the larger molecule one part at a time. The following structure of Streptogramin A provides an example.



A natural antibacterial compound that blocks protein synthesis at the 70S ribosomes of Gram-positive bacteria.

We have not said much about how overall shape influences the ability of one molecule to interact with another, in the sense that a key fits in a lock or a hand fits in a glove.



This type of consideration is also extremely important, and will follow with relative ease if you have worked hard to understand the general principles of structure outlined here and expanded upon in the early chapters of *Organic Chemistry*. An example would be the following. Streptogramin A, shown above, interacts in a hand-in-glove fashion with the 70S ribosome in bacteria to inhibit binding of transfer RNA at the ribosome. The result of this interaction is the prevention of protein synthesis in the bacterium, which thus accounts for the antibacterial effect of Streptogramin A. Other examples of hand-in-glove interactions include the olfactory response to geraniol mentioned earlier, and the action of enzymes to speed up the rate of reactions in biochemical systems.

### FINISHING THE PUZZLE

In conclusion, if you pay attention to learning aspects of structure during this initial period of "getting your feet wet" in organic chemistry, much of the three-dimensional aspects of molecules will become second nature to you. You will immediately recognize when a molecule is tetrahedral, trigonal planar, or linear in one region or another. You will see the potential for interaction between a given section of a molecule and that of another molecule based on their shape and polarity, and you will understand why many reactions take place. Ultimately, you will find that there is much less to memorize in organic chemistry than you first thought. You will learn how to put the pieces of the organic puzzle together, and see that structure is indeed almost everything, just applied in different situations!

## ACKNOWLEDGMENTS

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We are very grateful to Professor John Thompson of Texas A&M University—Kingsville for completing the arduous task of creating almost all of the structures found in this Study Guide.

T. W. Graham Solomons

C. B. Fryhle

R. G. Johnson

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# 1

## CARBON COMPOUNDS AND CHEMICAL BONDS

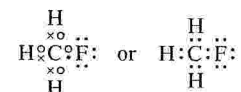
### SOLUTIONS TO PROBLEMS

#### Another Approach to Writing Lewis Structures

When we write Lewis structures using this method, we assemble the molecule or ion from the constituent atoms showing only the valence electrons (i.e., the electrons of the outermost shell). By having the atoms share electrons, we try to give each atom the electronic structure of a noble gas. For example, we give hydrogen atoms two electrons because this gives them the structure of helium. We give carbon, nitrogen, oxygen, and fluorine atoms eight electrons because this gives them the electronic structure of neon. The number of valence electrons of an atom can be obtained from the periodic table because it is equal to the group number of the atom. Carbon, for example, is in group 4A and has four valence electrons; fluorine, in group 7A, has seven; hydrogen, in group 1A, has one. As an illustration, let us write the Lewis structure for  $\text{CH}_3\text{F}$ . In the example below, we will at first show a hydrogen's electron as x, carbon's electrons as o's, and fluorine's electrons as dots.

#### Example A

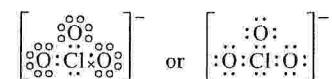
$3 \text{ H}^{\times}$ ,  $\text{o}\overset{\text{o}}{\underset{\text{o}}{\text{C}}}\text{o}$ , and  $\cdot\ddot{\text{F}}\cdot$  are assembled as



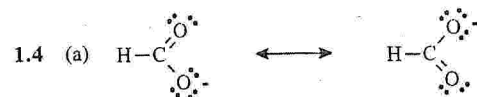
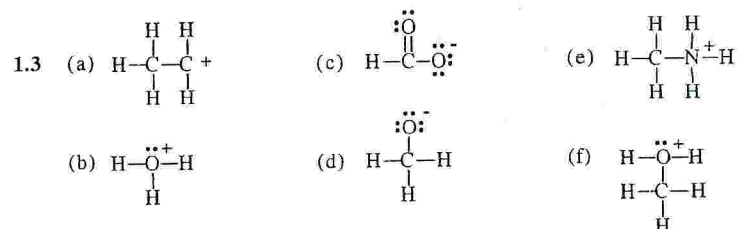
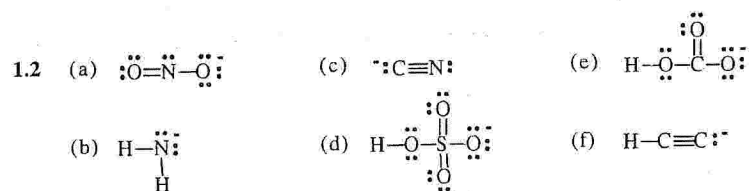
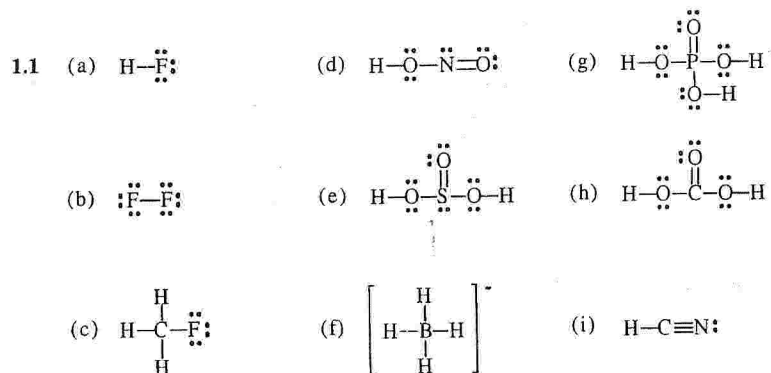
If the structure is an ion, we add or subtract electrons to give it the proper charge. As an example, consider the chlorate ion,  $\text{ClO}_3^-$ .

#### Example B

$:\ddot{\text{Cl}}\cdot$ , and  $\text{o}\overset{\text{o}}{\underset{\text{o}}{\text{O}}}\text{o}$  and an extra electron  $\times$  are assembled as

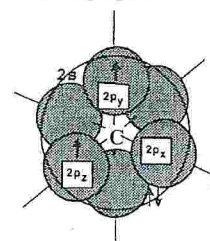






(b) and (c). Since the two resonance structures are equivalent, each should make an equal contribution to the overall hybrid. The C—O bonds should therefore be of equal length (they should be of bond order 1.5), and each oxygen atom should bear a 0.5 negative charge.

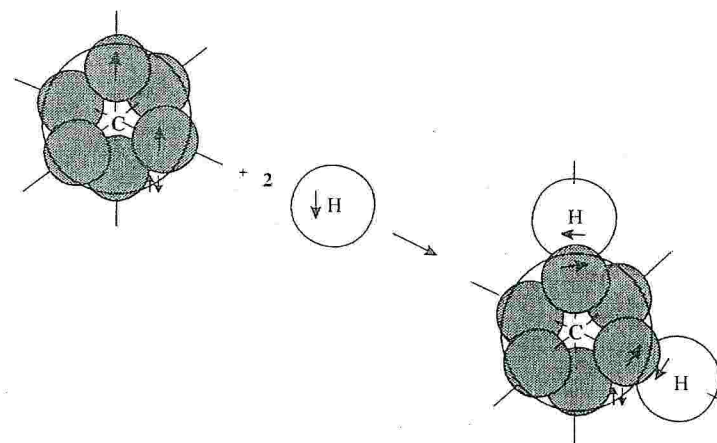
- 1.5 (a) In its ground state, the valence electrons of carbon might be disposed as shown in the following figure.



The electronic configuration of a ground state carbon atom. The  $p$  orbitals are designated  $2p_x$ ,  $2p_y$ , and  $2p_z$  to indicate their respective orientations along the  $x$ ,  $y$ , and  $z$  axes. The assignment of the unpaired electrons to the  $2p_x$  and  $2p_y$  orbitals is arbitrary. They could also have been placed in the  $2p_x$  and  $2p_z$  or  $2p_y$  and  $2p_z$  orbitals. (To have placed them both in the same orbital would not have been correct, however, for this would have violated Hund's rule.) (Section 1.10.)

The formation of the covalent bonds of methane from individual atoms requires that the carbon atom overlap its orbitals containing *single electrons* with  $1s$  orbitals of hydrogen atoms (which also contain a single electron). If a ground state carbon atom were to combine with hydrogen atoms in this way, the result would be that depicted below. *Only two carbon-hydrogen bonds would be formed, and these would be at right angles to each other.*

The hypothetical formation of  $\text{CH}_2$  from a carbon atom in its ground state.

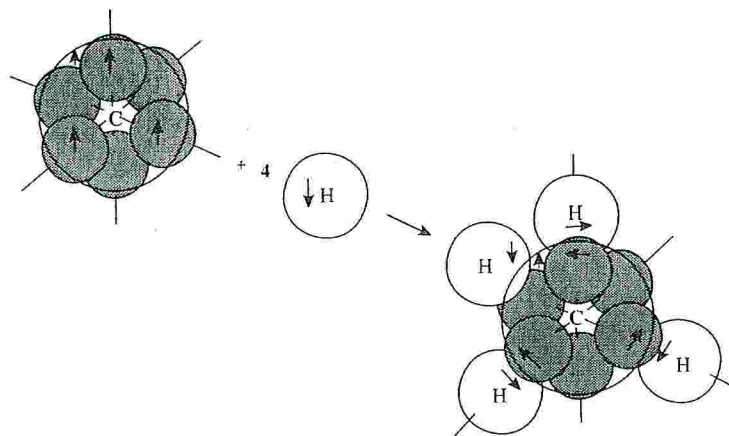


- (b) An excited-state carbon atom might combine with four hydrogen atoms as shown in the figure above.

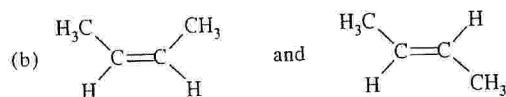
The promotion of an electron from the  $2s$  orbital to the  $2p_z$  orbital requires energy. The amount of energy required has been determined and is equal to  $400 \text{ kJ mol}^{-1}$ . This expenditure of energy can be rationalized by arguing that the energy released when two additional covalent bonds form would more than compensate for that required to excite the electron. No doubt this is true, but it solves only one problem. The problems that cannot be solved by using an excited-state carbon as a basis for a model of methane are the problems of the carbon-hydrogen bond angles and the apparent equivalence of

all four carbon-hydrogen bonds. Three of the hydrogens—those overlapping their  $1s$  orbitals with the three  $p$  orbitals—would, in this model, be at angles of  $90^\circ$  with respect to each other; the fourth hydrogen, the one overlapping its  $1s$  orbital with the  $2s$  orbital of carbon, would be at some other angle, probably as far from the other bonds as the confines of the molecule would allow. Basing our model of methane on this excited state of carbon gives us a carbon that is tetravalent *but one that is not tetrahedral*, and it predicts a structure for methane in which one carbon-hydrogen bond differs from the other three.

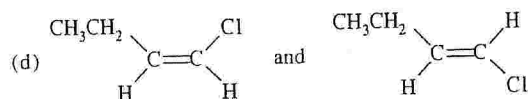
The hypothetical formation of  $\text{CH}_4$  from an excited-state carbon atom.



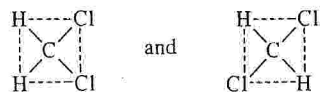
- 1.6 (a) Cis-trans isomers are not possible.



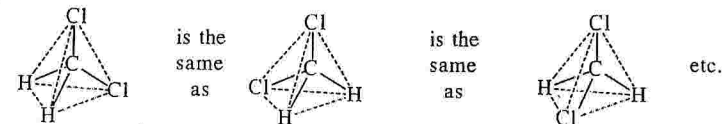
- (c) Cis-trans isomers are not possible.



- 1.7 If the geometry of the carbon atom were square planar, two isomeric compounds with the formula  $\text{CH}_2\text{Cl}_2$  should exist.

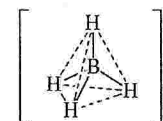


The fact that only one form of  $\text{CH}_2\text{Cl}_2$  has ever been detected supports a tetrahedral geometry for carbon, because with a tetrahedral geometry only one compound with the formula  $\text{CH}_2\text{Cl}_2$  is possible. All of the following structures are just different orientations of the same molecule.

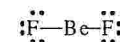


Make models to convince yourself of this fact.

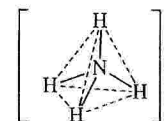
- 1.8 (a) There are four bonding pairs. The geometry is tetrahedral.



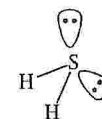
- (b) There are two bonding pairs about the central atom. The geometry is linear.



- (c) There are four bonding pairs. The geometry is tetrahedral.



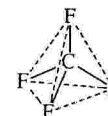
- (d) There are two bonding pairs and two nonbonding pairs. The geometry is angular.



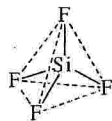
- (e) There are three bonding pairs. The geometry is trigonal planar.



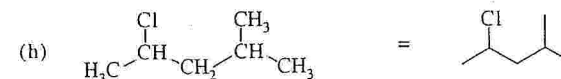
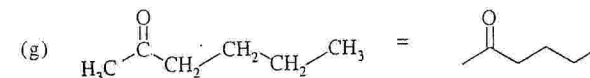
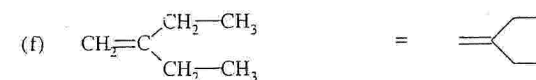
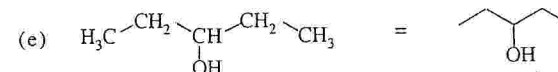
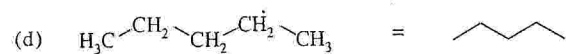
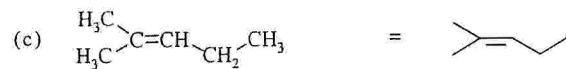
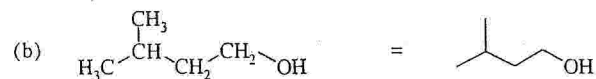
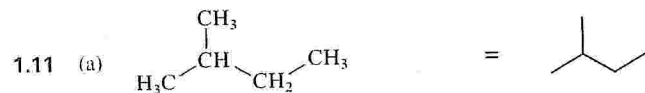
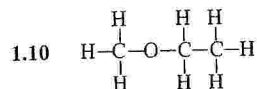
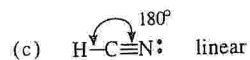
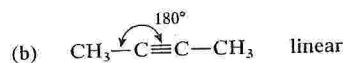
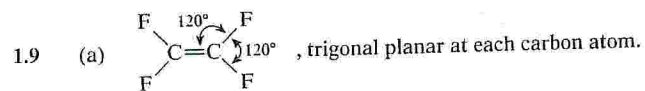
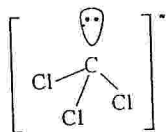
- (f) There are four bonding pairs around the central atom. The geometry is tetrahedral.



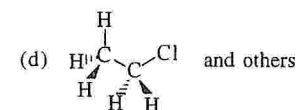
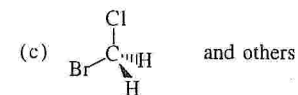
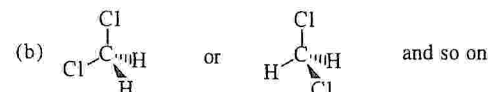
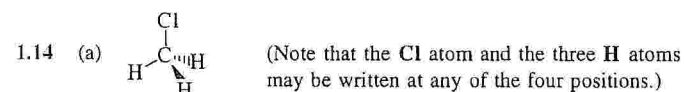
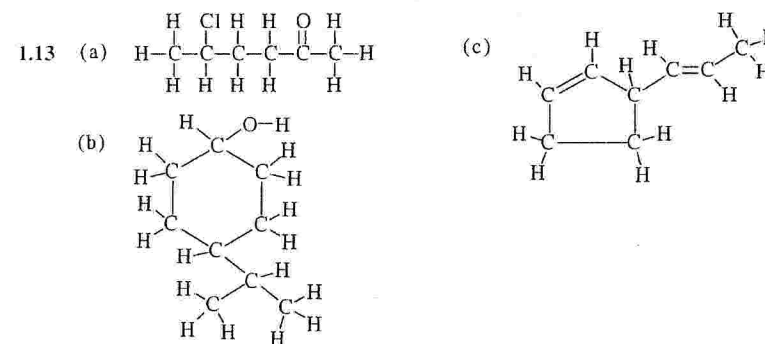
(g) There are four bonding pairs around the central atom. The geometry is tetrahedral.



(h) There are three bonding pairs and one nonbonding pair around the central atom. The geometry is trigonal pyramidal.

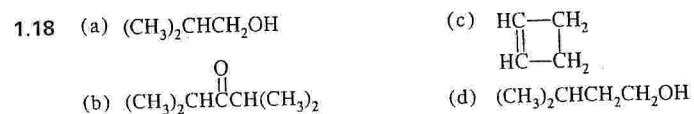
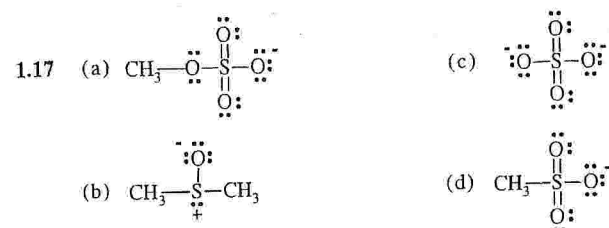
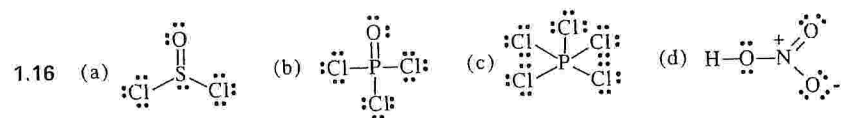


- 1.12 (a) and (d) are constitutional isomers with the molecular formula  $C_5H_{12}$ .  
 (b) and (e) are constitutional isomers with the molecular formula  $C_5H_{12}O$ .  
 (c) and (f) are constitutional isomers with the molecular formula  $C_6H_{12}$ .

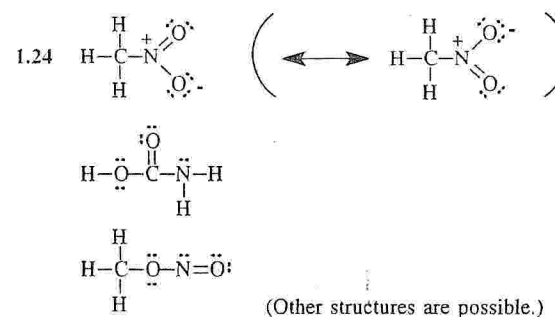
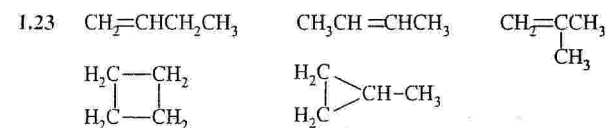
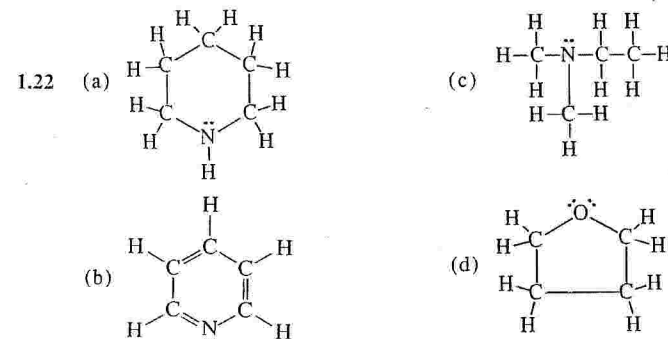
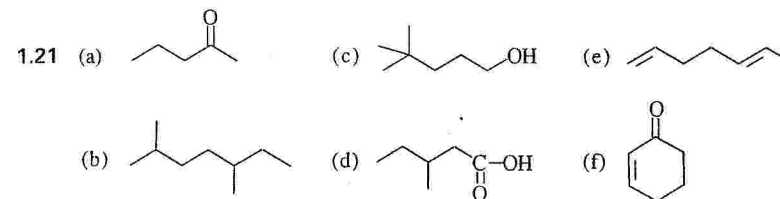




- 1.15 (a)  $\text{Na}^+$  has the electronic configuration,  $1s^2 2s^2 2p^6$ , of Ne.  
 (b)  $\text{Cl}^-$  has the electronic configuration,  $1s^2 2s^2 2p^6 3s^2 3p^6$ , of Ar.  
 (c)  $\text{F}^+$  and (h)  $\text{Br}^+$  do not have the electronic configuration of a noble gas.  
 (d)  $\text{H}^-$  has the electronic configuration,  $1s^2$ , of He.  
 (e)  $\text{Ca}^{2+}$  has the electronic configuration,  $1s^2 2s^2 2p^6 3s^2 3p^6$  of Ar.  
 (f)  $\text{S}^{2-}$  has the electronic configuration,  $1s^2 2s^2 2p^6 3s^2 3p^6$  of Ar.  
 (g)  $\text{O}^{2-}$  has the electronic configuration,  $1s^2 2s^2 2p^6$  of Ne.



- 1.20 (a) Different compounds, not isomeric  
 (b) Constitutional isomers  
 (c) Same compound  
 (d) Same compound  
 (e) Same compound  
 (f) Constitutional isomers  
 (g) Different compounds, not isomeric  
 (h) Same compound  
 (i) Different compounds, not isomeric  
 (j) Same compound  
 (k) Constitutional isomers  
 (l) Different compounds, not isomeric  
 (m) Same compound  
 (n) Same compound  
 (o) Same compound  
 (p) Constitutional isomers



- 1.25 (a) While the structures differ in the position of their electrons, they also differ in the positions of their nuclei and thus they are not resonance structures. (In cyanic acid the hydrogen nucleus is bonded to oxygen; in isocyanic acid it is bonded to nitrogen.)  
 (b) The anion obtained from either acid is a resonance hybrid of the following structures:  $\text{:}\ddot{\text{O}}\text{--C}\equiv\text{N:} \longleftrightarrow \text{:}\ddot{\text{O}}\text{=C}\equiv\text{N:}^-$

1.26



- (a) A + charge. ( $F = 4 - \frac{1}{2} = +1$ )

(b)  $A^+$  charge. (It is called a methyl cation.)

(c) Trigonal planar, that is,



- (d)  $sp^2$

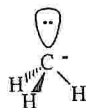


1.27

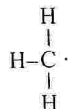
- (a) A - charge. ( $F = 4 - \frac{1}{2} - 2 = -1$ )

(b) A  $-$  charge. (It is called a methyl anion.)

(c) Trigonal pyramidal, that is



- (d)  $sp^3$

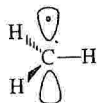


1.28

- (a) No formal charge. ( $F = 4 - \frac{1}{2} - 1 = 0$ )

(b) No charge.

(c)  $sp^2$ , that is,

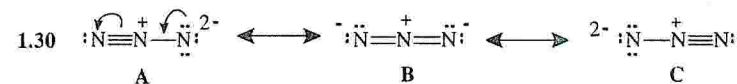


1.29 (a) and (b)

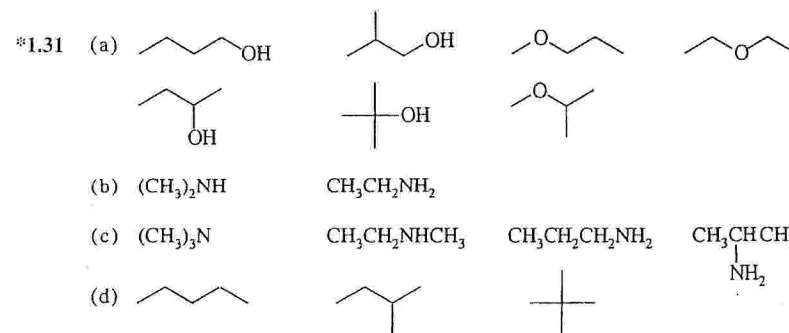


- (c) Because the two resonance structures are equivalent, they should make equal contributions to the hybrid and, therefore, the bonds should be the same length.

(d) Yes. We consider the central atom to have two groups or units of bonding electrons and one unshared pair.



- Structures A and C are equivalent and, therefore, make equal contributions to the hybrid. The bonds of the hybrid, therefore, have the same length.



- \*1.32 (a) constitutional isomers

(b) the same

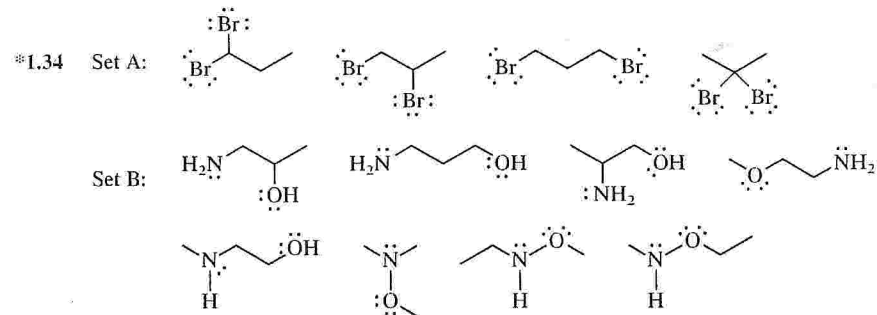
(d) constitutional isomers

(f) the same

- \*1.33 (a)  $\text{:O}=\text{N}=\text{O:}$

(b) Linear

(c) Carbon dioxide

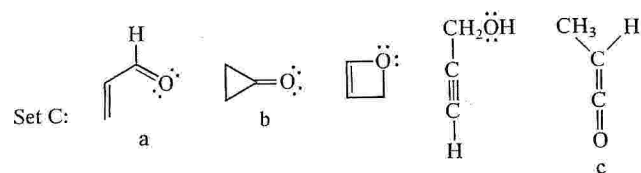


- \*1.34 Set A

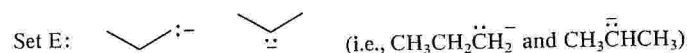
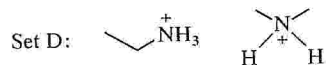
Set A

Set B

Set B



[and unstable enol forms of a, b, and c]



## QUIZ

1.1 Which of the following is a valid Lewis dot formula for the nitrite ion ( $\text{NO}_2^-$ )?

- (a)  $\text{:}\ddot{\text{O}}-\ddot{\text{N}}=\ddot{\text{O}}\text{:}$  (b)  $\text{:}\ddot{\text{O}}=\ddot{\text{N}}-\ddot{\text{O}}\text{:}$  (c)  $\text{:}\ddot{\text{O}}-\ddot{\text{N}}=\ddot{\text{O}}\text{:}$  (d) Two of these  
(e) None of the above

1.2 What is the hybridization state of the boron atom in  $\text{BF}_3$ ?

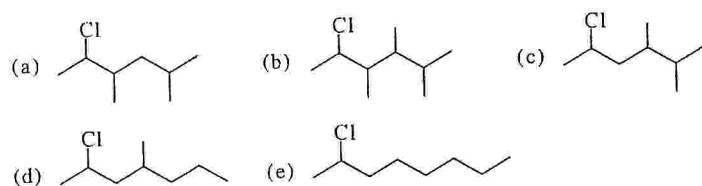
- (a)  $s$  (b)  $p$  (c)  $sp$  (d)  $sp^2$  (e)  $sp^3$

1.3  $\text{BF}_3$  reacts with  $\text{NH}_3$  to produce a compound,  $\text{F}-\text{B}(\text{F})_2-\text{N}(\text{H})_3$ . The hybridization state of B is

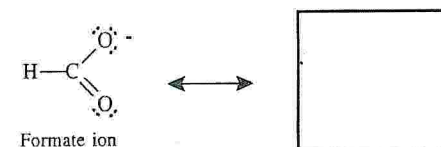
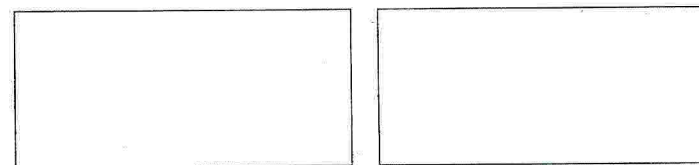
- (a)  $s$  (b)  $p$  (c)  $sp$  (d)  $sp^2$  (e)  $sp^3$

1.4 The formal charge on N in the compound given in Problem 1.3 is

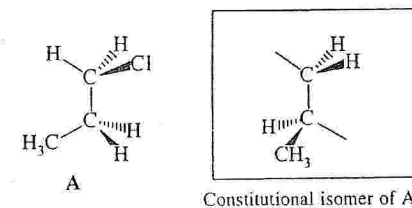
- (a) -2 (b) -1 (c) 0 (d) +1 (e) +2

1.5 The correct bond-line formula of the compound whose condensed formula is  $\text{CH}_3\text{CHClCH}_2\text{CH}(\text{CH}_3)\text{CH}(\text{CH}_3)_2$  is

1.6 Write another resonance structure for the formate ion.

1.7 In the boxes below write condensed structural formulas for constitutional isomers of  $\text{CH}_3(\text{CH}_2)_3\text{CH}_3$ .

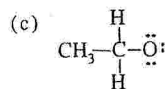
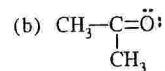
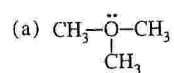
1.8 Write a three-dimensional formula for a constitutional isomer of compound A given below. Complete the partial structure shown.

1.9 Consider the molecule  $(\text{CH}_3)_3\text{B}$  and give the following:

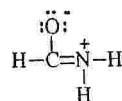
- (a) Hybridization state of boron
- (b) Hybridization state of carbon atoms
- (c) Formal charge on boron
- (d) Orientation of groups around boron
- (e) Dipole moment of  $(\text{CH}_3)_3\text{B}$



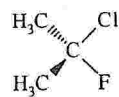
1.10 Give the formal charge on oxygen in each compound.



1.11 Write another resonance structure in which all of the atoms have a formal charge of zero.



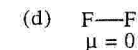
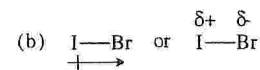
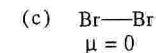
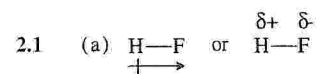
1.12 Indicate the direction of the net dipole moment of the following molecule.



## 2

## REPRESENTATIVE CARBON COMPOUNDS: FUNCTIONAL GROUPS, INTERMOLECULAR FORCES, AND INFRARED (IR) SPECTROSCOPY

### SOLUTIONS TO PROBLEMS

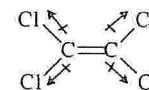


2.2 VSEPR theory predicts a planar structure for  $\text{BF}_3$ .

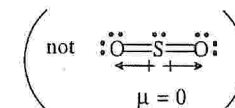
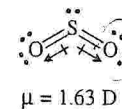


The vector sum of the bond moments of a trigonal planar structure would be zero, resulting in a prediction of  $\mu = 0$  for  $\text{BF}_3$ . This correlates with the experimental observation and confirms the prediction of VSEPR theory.

2.3 The shape of  $\text{CCl}_2=\text{CCl}_2$  (below) is such that the vector sum of all of the  $\text{C}-\text{Cl}$  bond moments is zero.

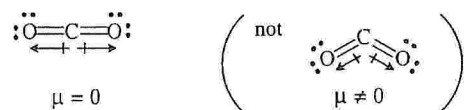


2.4 The fact that  $\text{SO}_2$  has a dipole moment indicates that the molecule is angular, not linear.

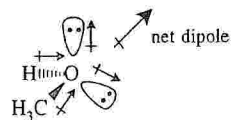


An angular shape is what we would expect from VSEPR theory, too.

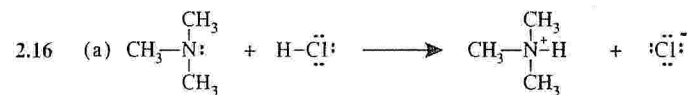
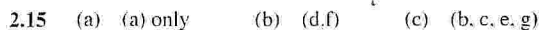
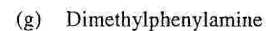
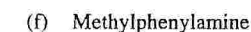
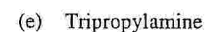
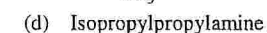
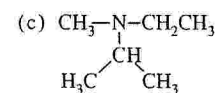
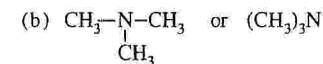
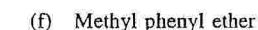
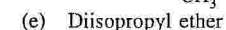
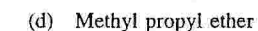
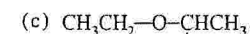
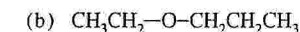
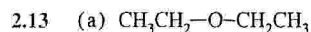
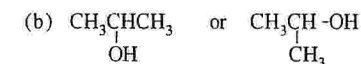
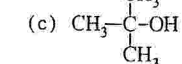
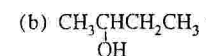
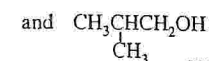
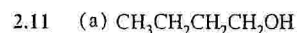
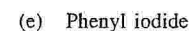
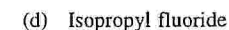
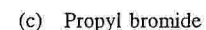
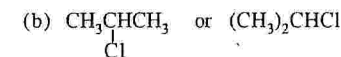
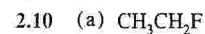
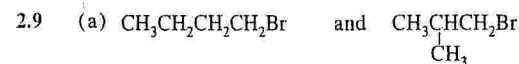
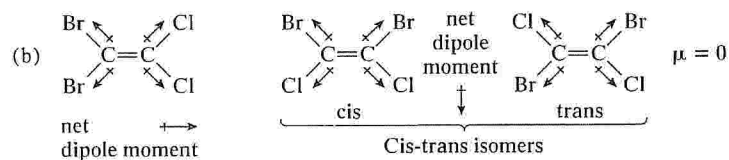
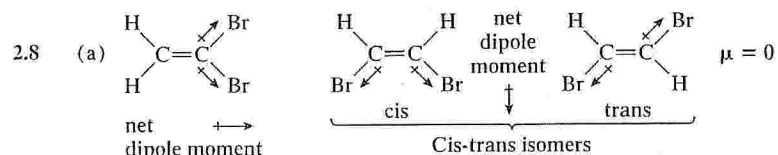
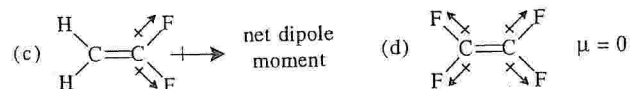
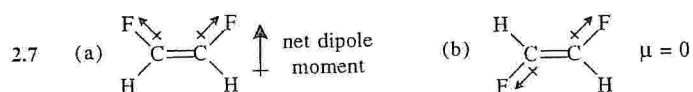
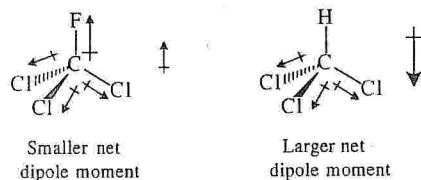
The fact that  $\text{CO}_2$  has no dipole moment indicates that its shape is linear, not angular.



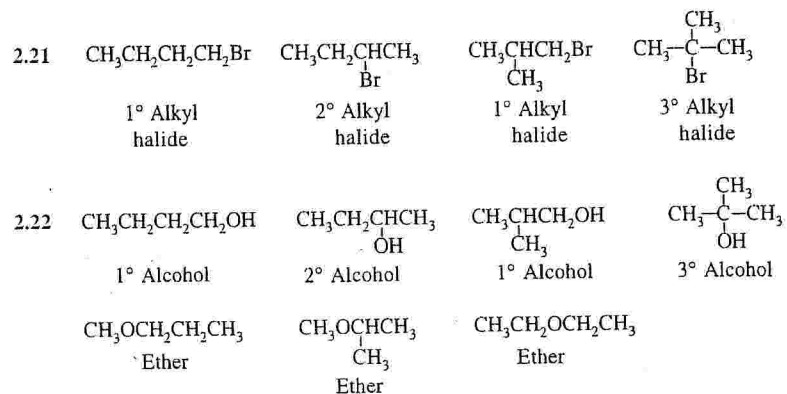
2.5 Again, this is what VSEPR theory predicts.



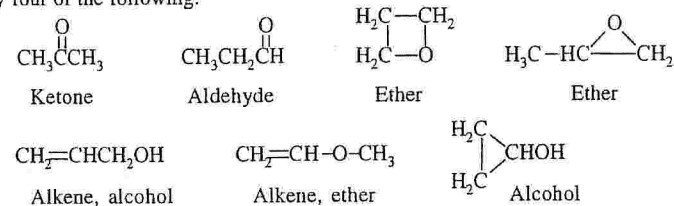
2.6 In  $\text{CFCl}_3$  the large  $\text{C}-\text{F}$  bond moment opposes the  $\text{C}-\text{Cl}$  moments, leading to a net dipole moment in the direction of the fluorine. Because hydrogen is much less electronegative than fluorine no such opposing effect occurs in  $\text{CHCl}_3$ ; therefore, it has a net dipole moment that is larger and in the direction of the chlorine atoms.



- 2.17 (a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$  would boil higher because its molecules can form hydrogen bonds to each other through the  $-\ddot{\text{O}}-\text{H}$  group.
- (b)  $\text{CH}_3\text{CH}_2\text{NHCH}_3$  would boil higher because its molecules can form hydrogen bonds to each other through the  $-\ddot{\text{N}}-\text{H}$  group.
- (c)  $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{OH}$  because by having two  $-\ddot{\text{O}}-\text{H}$  groups, it can form more hydrogen bonds.
- 2.18 Cyclopropane would have the higher melting point because its cyclic structure gives it a rigid compact shape that would permit stronger crystal lattice forces.
- 2.19 (a) Ketone (b) Alkyne (c) Alcohol (d) Aldehyde  
(e) Alcohol (f) Alkene
- 2.20 (a) Three carbon-carbon double bonds (alkene) and a  $2^\circ$  alcohol  
(b) Phenyl, carboxylic acid, amide, ester, and a  $1^\circ$  amine  
(c) Phenyl and a  $1^\circ$  amine  
(d) Carbon-carbon double bond and a  $2^\circ$  alcohol  
(e) Phenyl, ester, and a  $3^\circ$  amine  
(f) Carbon-carbon double bond and an aldehyde  
(g) Carbon-carbon double bond and 2 ester groups

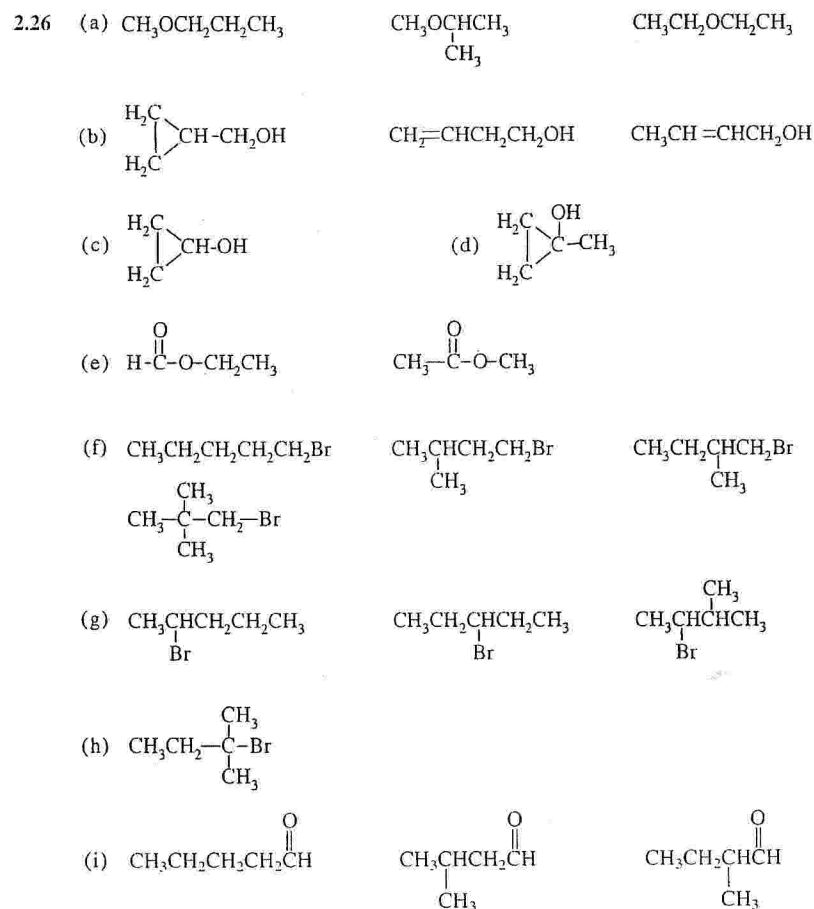


- 2.23 Any four of the following:

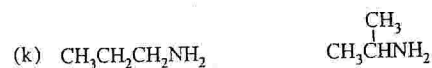
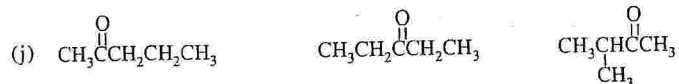


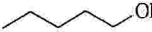
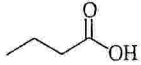
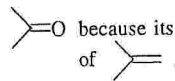
- 2.24 (a)
- $1^\circ$
- (b)
- $2^\circ$
- (c)
- $3^\circ$
- (d)
- $3^\circ$
- (e)
- $2^\circ$

- 2.25 (a)
- $2^\circ$
- (b)
- $1^\circ$
- (c)
- $3^\circ$
- (d)
- $2^\circ$
- (e)
- $2^\circ$
- (f)
- $3^\circ$







- 2.27 (a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$  because its molecules can form hydrogen bonds to each other through its  $\text{O}-\text{H}$  group.
- (b)  $\text{HOCH}_2\text{CH}_2\text{OH}$  because with two  $\text{O}-\text{H}$  groups, its molecules can form more hydrogen bonds with each other.
- (c)   $\text{OH}$  because its molecules can form hydrogen bonds to each other.
- (d)   $\text{OH}$  [Same reason as (c)].
- (e)  because its molecules can form hydrogen bonds to each other through its  $\text{N}-\text{H}$  group.
- (f)  because its molecules will have a larger dipole moment. (The trans compound will have  $\mu = 0$ .)
- (g)   $\text{OH}$  [Same reason as (c)].
- (h) Nonane, because of its larger molecular weight and larger size, will have larger van der Waals attractions.
- (i)  because its carbonyl group is far more polar than the double bond of .

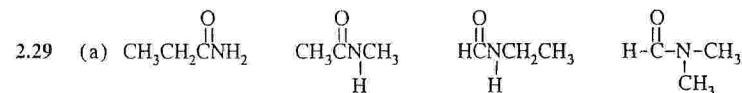
- 2.28 (a) The alcohol would have a broad absorption from the  $\text{O}-\text{H}$  group in the 3200 to 3500  $\text{cm}^{-1}$  region of its IR spectrum. The ether would have no such absorption.
- (c) The ketone would have a strong absorption from its carbonyl group near 1700  $\text{cm}^{-1}$  in its IR spectrum. The alcohol would have a broad absorption due to its hydroxyl group in the 3200 to 3500  $\text{cm}^{-1}$  region of its IR spectrum.

(d) Same rationale as for (a)

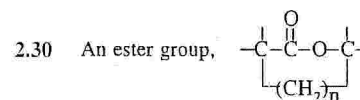
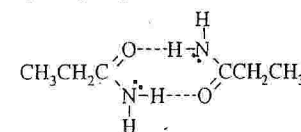
(e) The secondary amine would have an absorption near 3300 to 3500  $\text{cm}^{-1}$  arising from  $\text{N}-\text{H}$  stretching. The tertiary amine would have no such absorption in this region since there is no  $\text{N}-\text{H}$  group present.

(g) Both compounds would exhibit absorptions near 1710 to 1780  $\text{cm}^{-1}$  due to carbonyl stretching vibrations. The carboxylic acid would also have a broad absorption somewhere between 2500 and 3500  $\text{cm}^{-1}$  due to its hydroxyl group. The ester would not have a hydroxyl absorption.

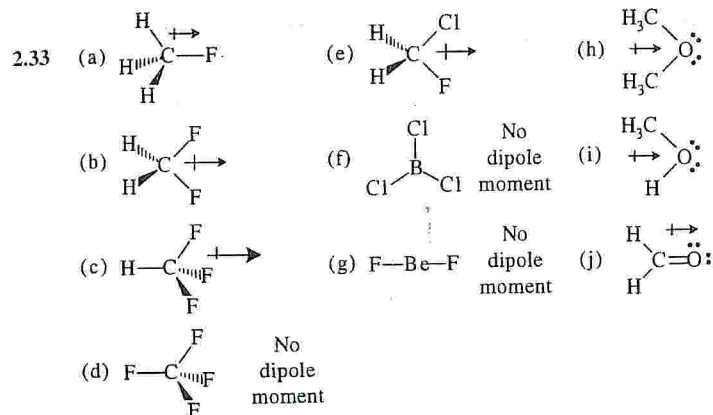
(i) The ketone would have a strong absorption from its carbonyl group near 1700  $\text{cm}^{-1}$  in its IR spectrum. The alkene would have no such absorption but would have an absorption between 1620 and 1680  $\text{cm}^{-1}$  due to  $\text{C}=\text{C}$  stretching.



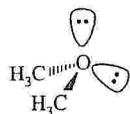
(b) The last one given above [i.e.,  $\text{HCN}(\text{CH}_3)_3$ ] because it does not have a hydrogen that is covalently bonded to nitrogen and, therefore, its molecules cannot form hydrogen bonds to each other. The other molecules all have a hydrogen covalently bonded to nitrogen and, therefore, hydrogen-bond formation is possible. With the first molecule, for example, hydrogen bonds could form in the following way:



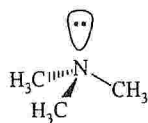
- 2.31 The attractive forces between hydrogen fluoride molecules are the very strong dipole-dipole attractions that we call *hydrogen bonds*. (The partial positive charge of a hydrogen fluoride molecule is relatively exposed because it resides on the hydrogen nucleus. By contrast, the positive charge of an ethyl fluoride molecule is buried in the ethyl group and is shielded by the surrounding electrons. Thus the positive end of one hydrogen fluoride molecule can approach the negative end of another hydrogen fluoride molecule much more closely, with the result that the attractive force between them is much stronger.)
- 2.32 (a) and (b) are polar and hence are able to dissolve ionic compounds. (c) and (d) are non-polar and will not dissolve ionic compounds.



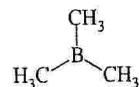
- 2.34 (a) Dimethyl ether: There are four electron pairs around the central oxygen: two bonding pairs and two nonbonding pairs. We would expect  $sp^3$  hybridization of the oxygen with a bond angle of approximately  $109.5^\circ$  between the methyl groups.



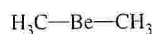
- (b) Trimethylamine: There are four electron pairs around the central nitrogen: three bonding pairs and one nonbonding pair. We would expect  $sp^3$  hybridization of the nitrogen with a bond angle of approximately  $109.5^\circ$  between the methyl groups.



- (c) Trimethylboron: There are only three bonding electron pairs around the central boron. We would expect  $sp^2$  hybridization of the boron with a bond angle of  $120^\circ$  between the methyl groups.

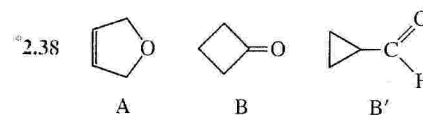
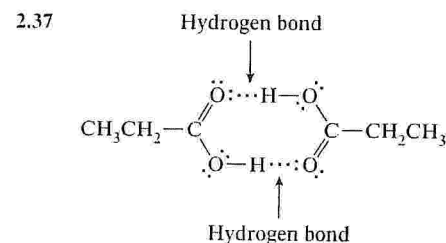
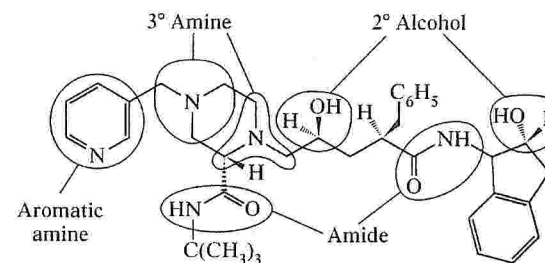


- (d) Dimethylberyllium: There are only two bonding electron pairs around the central beryllium atom. We would expect  $sp$  hybridization of the beryllium atom with a bond angle of  $180^\circ$  between the methyl groups.

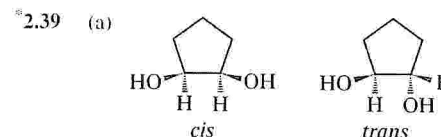


- 2.35 Without one (or more) polar bonds, a molecule cannot possess a dipole moment and, therefore, it cannot be polar. If the bonds are directed so that the bond moments cancel, however, the molecule will not be polar even though it has polar bonds.

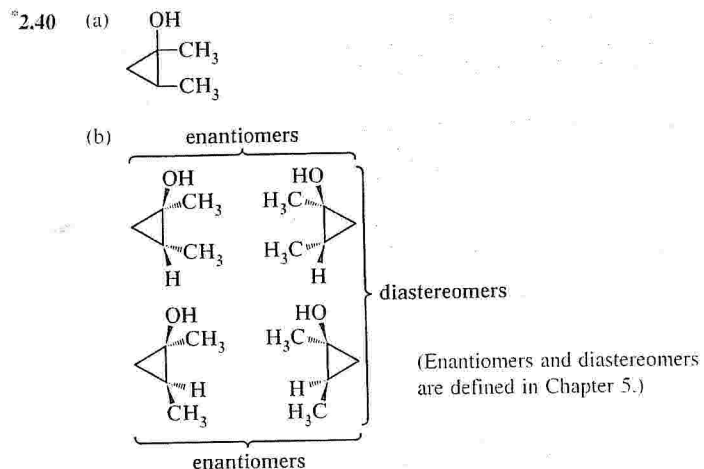
- 2.36 Crixivan has the following functional groups:



The  $1780\text{-cm}^{-1}$  band is in the general range for  $\text{C}=\text{O}$  stretching so structure B' is considered one of the possible answers, but only B would have its  $\text{C}=\text{O}$  stretch at this high frequency (B' would be at about  $1730\text{ cm}^{-1}$ ).



- (b) The *cis* isomer will have the  $3572\text{-cm}^{-1}$  band because only in it are the two hydroxyl groups close enough to permit intramolecular hydrogen-bonding. (Intermolecular hydrogen-bonding is not possible at high dilution in a non-polar solvent like  $\text{CCl}_4$ .)



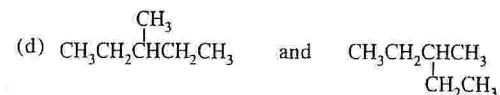
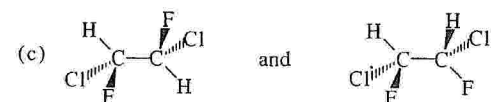
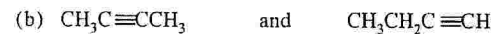
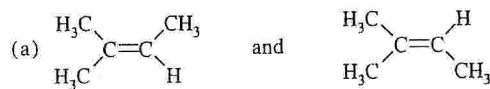
## QUIZ

2.1 Which of the following pairs of compounds is *not* a pair of constitutional isomers?

- (a)  $\text{CH}_3\text{---O---CH=CH}_2$  and  $\text{CH}_3\text{CH}_2\overset{\text{O}}{\underset{\text{||}}{\text{C}}}\text{H}$
- (b)  and  $\text{CH}_3\text{CH=CHCH}_2\text{CH}_3$
- (c)  $\text{CH}_3\overset{\text{O}}{\underset{\text{||}}{\text{C}}}\text{---OH}$  and  $\text{HO---CH}_2\overset{\text{O}}{\underset{\text{||}}{\text{C}}}\text{H}$
- (d)  $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$  and  $\text{CH}_3\text{CH=C=CH}_2$
- (e)  $\text{CH}_3\underset{\text{CH}_3}{\underset{|}{\text{CH}}}\text{CH(CH}_3)_2$  and  $(\text{CH}_3)_2\text{CHCH(CH}_3)_2$

2.2 Which of the answers to Problem 2.1 contains an ether group?

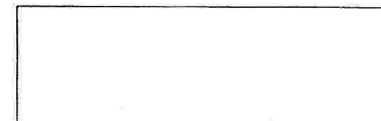
2.3 Which of the following pairs of structures represents a pair of isomers?



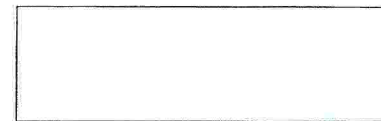
(e) More than one of these pairs are isomers.

2.4 Give a structural formula for each of the following:

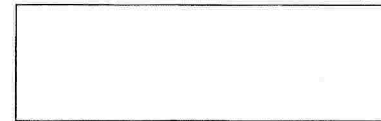
(a) A tertiary alcohol with the formula  $\text{C}_5\text{H}_{12}\text{O}$



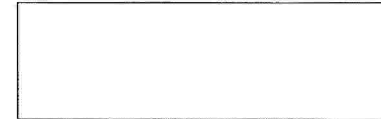
(b) An *N,N*-disubstituted amide with the formula  $\text{C}_4\text{H}_9\text{NO}$



(c) The alkene isomer of  $\text{C}_2\text{H}_2\text{Cl}_2$  that has no dipole moment



(d) An ester with the formula  $\text{C}_2\text{H}_4\text{O}_2$



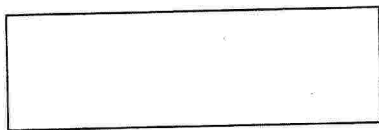
(e) The isomer of  $\text{C}_2\text{H}_2\text{Cl}_2$  that cannot show cis-trans isomerism



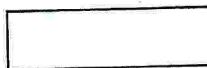
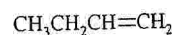
(f) The isomer of  $\text{C}_3\text{H}_8\text{O}$  that would have the lowest boiling point



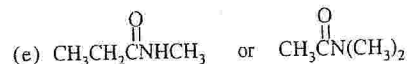
(g) The isomer of  $C_4H_{11}N$  that would have the lowest boiling point



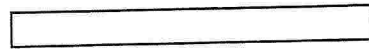
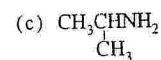
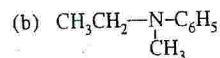
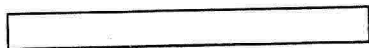
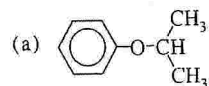
- 2.5 Write the bond-line formula for a constitutional isomer of the compound shown below that does not contain a double bond.



- 2.6 Circle the compound in each pair that would have the higher boiling point.



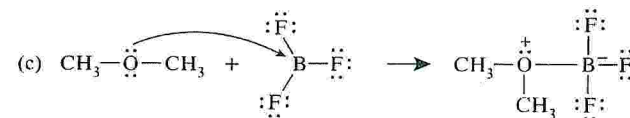
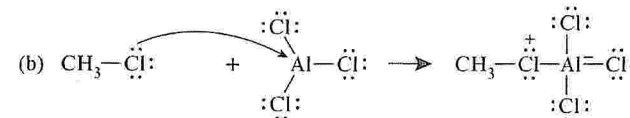
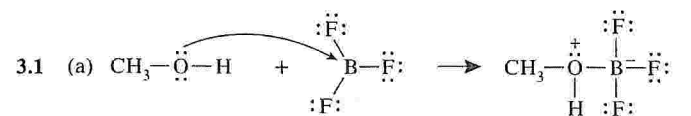
- 2.7 Give an acceptable name for each of the following:



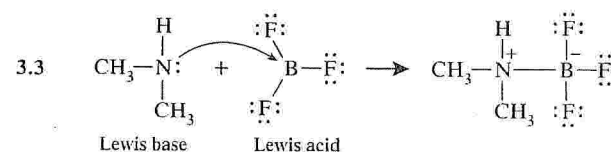
# 3

## AN INTRODUCTION TO ORGANIC REACTIONS: ACIDS AND BASES

### SOLUTIONS TO PROBLEMS



- 3.2 (a) Lewis base (b) Lewis acid  
(c) Lewis base (d) Lewis base  
(e) Lewis acid (f) Lewis base



3.4 (a)  $K_a = \frac{[H_3O^+][HCO_2^-]}{[HCO_2H]} = 1.77 \times 10^{-4}$

Let  $x = [H_3O^+] = [HCO_2^-]$  at equilibrium

then,  $0.1 - x = [HCO_2H]$  at equilibrium

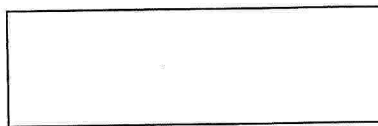
but, since the  $K_a$  is very small,  $x$  will be very small and  $0.1 - x \approx 0.1$

Therefore,

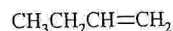
$$\begin{aligned} \frac{(x)(x)}{0.1} &= 1.77 \times 10^{-4} \\ x^2 &= 1.77 \times 10^{-5} \\ x &= 0.0042 = [H_3O^+] = [HCO_2^-] \end{aligned}$$



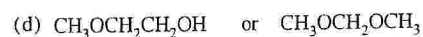
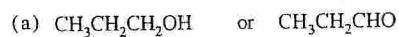
(g) The isomer of  $C_4H_{11}N$  that would have the lowest boiling point



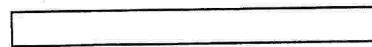
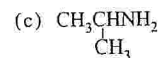
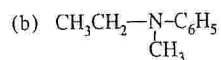
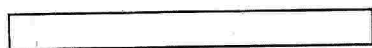
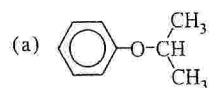
2.5 Write the bond-line formula for a constitutional isomer of the compound shown below that does not contain a double bond.



2.6 Circle the compound in each pair that would have the higher boiling point.



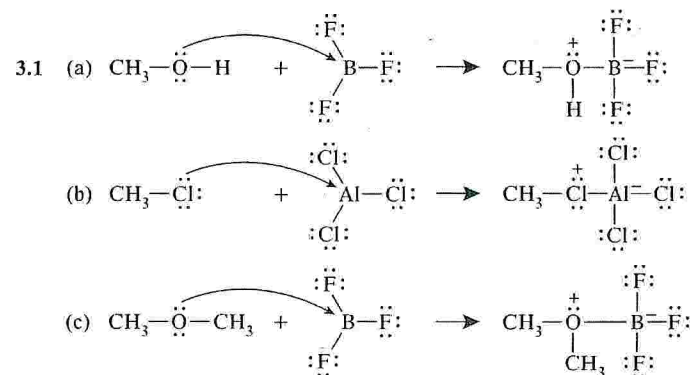
2.7 Give an acceptable name for each of the following:



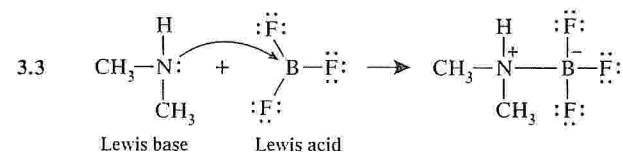
# 3

## AN INTRODUCTION TO ORGANIC REACTIONS: ACIDS AND BASES

### SOLUTIONS TO PROBLEMS



- 3.2 (a) Lewis base (b) Lewis acid  
(c) Lewis base (d) Lewis base  
(e) Lewis acid (f) Lewis base



3.4 (a)  $K_a = \frac{[H_3O^+][HCO_2^-]}{[HCO_2H]} = 1.77 \times 10^{-4}$

Let  $x = [H_3O^+] = [HCO_2^-]$  at equilibrium

then,  $0.1 - x = [HCO_2H]$  at equilibrium

but, since the  $K_a$  is very small,  $x$  will be very small and  $0.1 - x \approx 0.1$

Therefore,

$$\begin{aligned} \frac{(x)(x)}{0.1} &= 1.77 \times 10^{-4} \\ x^2 &= 1.77 \times 10^{-5} \\ x &= 0.0042 = [H_3O^+] = [HCO_2^-] \end{aligned}$$

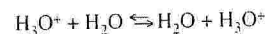
$$\begin{aligned} \text{(b) } \% \text{ Ionized} &= \frac{[\text{H}_3\text{O}^+]}{0.1} \times 100 \text{ or } \frac{[\text{HCO}_2^-]}{0.1} \times 100 \\ &= \frac{.0042}{0.1} \times 100 = 4.2\% \end{aligned}$$

$$3.5 \text{ (a) } \text{p}K_a = -\log 10^{-7} = -(-7) = 7$$

$$\text{(b) } \text{p}K_a = -\log 5.0 = -0.699$$

(c) Since the acid with a  $K_a = 5$  has a larger  $K_a$ , it is the stronger acid.

3.6 When  $\text{H}_3\text{O}^+$  acts as an acid in aqueous solution, the equation is



and  $K_a$  is

$$K_a = \frac{[\text{H}_2\text{O}][\text{H}_3\text{O}^+]}{[\text{H}_3\text{O}^+]} = [\text{H}_2\text{O}]$$

The molar concentration of  $\text{H}_2\text{O}$  in pure  $\text{H}_2\text{O}$ , that is,  $[\text{H}_2\text{O}] = 55.5$ ; therefore,  $K_a = 55.5$

The  $\text{p}K_a$  is

$$\text{p}K_a = -\log 55.5 = -1.74$$

3.7 The  $\text{p}K_a$  of the methylammonium ion is equal to 10.6 (Section 3.5C). Since the  $\text{p}K_a$  of the anilinium ion is equal to 4.6, the anilinium ion is a stronger acid than the methylammonium ion, and aniline ( $\text{C}_6\text{H}_5\text{NH}_2$ ) is a weaker base than methylamine ( $\text{CH}_3\text{NH}_2$ ).

3.8 (a) Negative. Because the atoms are constrained to one molecule in the product, they have to become more ordered.

(b) Approximately zero.

(c) Positive. Because the atoms are in two separate product molecules, they become more disordered.

$$3.9 \text{ (a) If } K_{eq} = 1$$

then,

$$\log K_{eq} = 0 = \frac{-\Delta G^\circ}{2.303RT}$$

$$\Delta G^\circ = 0$$

$$\text{(b) If } K_{eq} = 10$$

then,

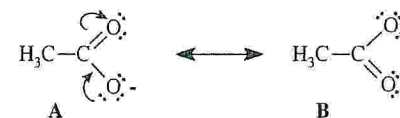
$$\log K_{eq} = 1 = \frac{-\Delta G^\circ}{2.303RT}$$

$$\Delta G^\circ = -(2.303)(0.008314 \text{ kJ mol}^{-1} \text{ K}^{-1})(298 \text{ K}) = -5.71 \text{ kJ mol}^{-1}$$

$$\text{(c) } \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$\Delta G^\circ = \Delta H^\circ = -5.71 \text{ kJ mol}^{-1} \text{ if } \Delta S^\circ = 0$$

3.10 Structures A and B make equal contributions to the overall hybrid. This means that the carbon-oxygen bonds should be the same length and that the oxygens should bear equal positive charges.



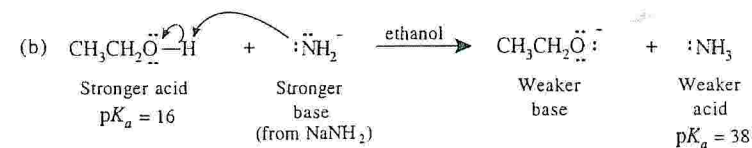
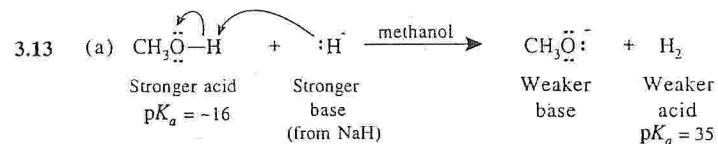
3.11 (a)  $\text{CHCl}_2\text{CO}_2\text{H}$  would be the stronger acid because the electron-withdrawing inductive effect of two chlorine atoms would make its hydroxyl proton more positive. The electron-withdrawing effect of the two chlorine atoms would also stabilize the dichloroacetate ion more effectively by dispersing its negative charge more extensively.

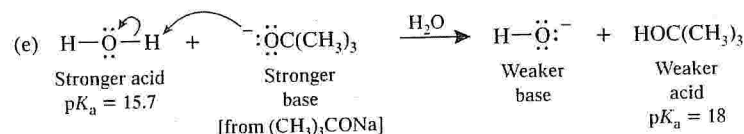
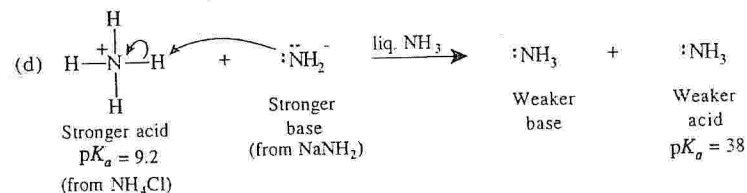
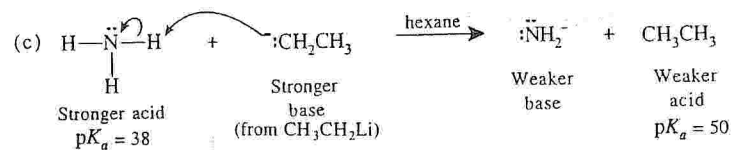
(b)  $\text{CCl}_3\text{CO}_2\text{H}$  would be the stronger acid for reasons similar to those given in (a), except here there are three versus two electron-withdrawing chlorine atoms involved.

(c)  $\text{CH}_2\text{FCO}_2\text{H}$  would be the stronger acid because the electron-withdrawing effect of a fluorine atom is greater than that of a bromine atom (fluorine is more electronegative).

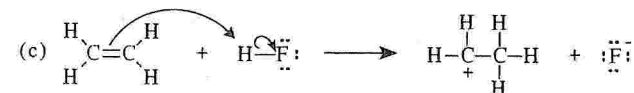
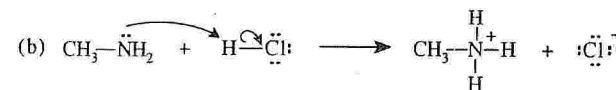
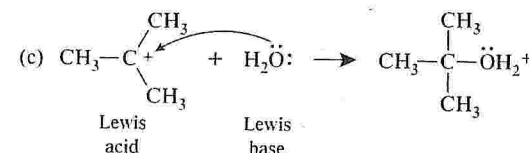
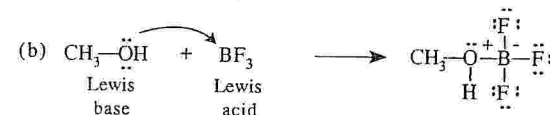
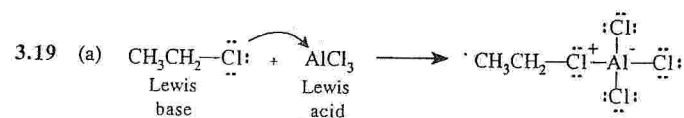
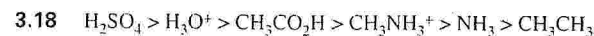
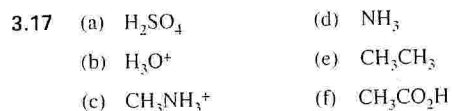
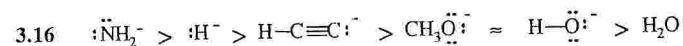
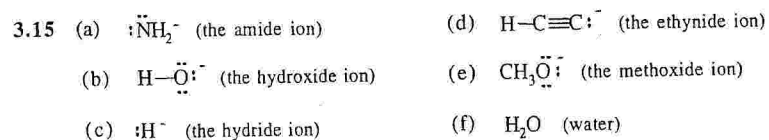
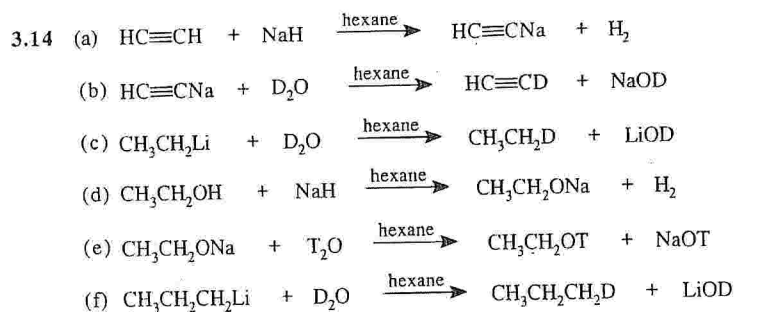
(d)  $\text{CH}_2\text{FCO}_2\text{H}$  is the stronger acid because the fluorine atom is nearer the carboxyl group and is, therefore, better able to exert its electron-withdrawing inductive effect. (*Remember:* Inductive effects weaken steadily as the distance between the substituent and the group increases.)

3.12 All compounds containing oxygen and most compounds containing nitrogen will have an unshared electron pair on their oxygen or nitrogen atom. These compounds can, therefore, act as bases and accept a proton from concentrated sulfuric acid. When they accept a proton, these compounds become either oxonium ions or ammonium ions, and having become ionic, they are soluble in the polar medium of sulfuric acid. The only nitrogen compounds that do not have an electron pair on their nitrogen atom are quaternary ammonium compounds, and these, already being ionic, also dissolve in the polar medium of concentrated sulfuric acid.

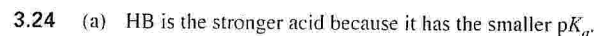
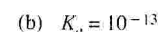
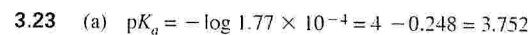
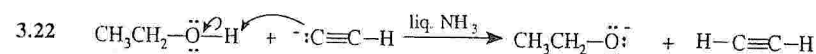




(f) No appreciable acid-base reaction would occur because  $\text{NaOH}$  is not a strong enough base to remove a proton from  $(\text{CH}_3)_3\text{COH}$ .

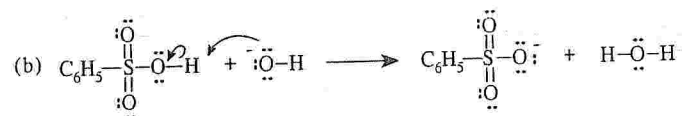
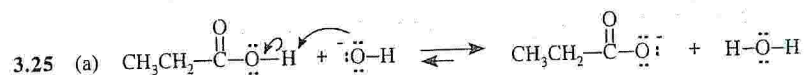


3.21 Because the proton attached to the highly electronegative oxygen atom of  $\text{CH}_3\text{OH}$  is much more acidic than the protons attached to the much less electronegative carbon atom.

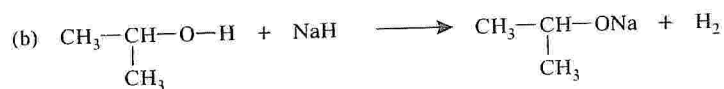
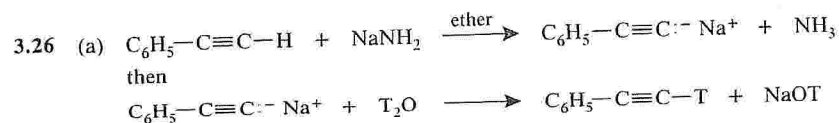
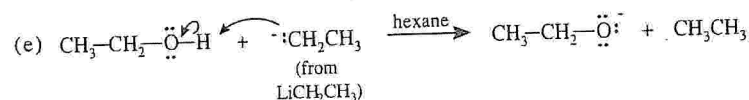
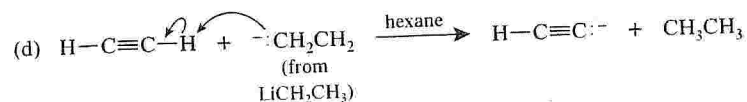


(b) Yes. Since  $\text{A}^-$  is the stronger base and  $\text{HB}$  is the stronger acid, the following acid-base reaction will take place.





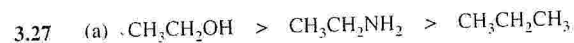
(c) No appreciable acid-base reaction takes place because  $\text{CH}_3\text{CH}_2\text{ONa}$  is too weak a base to remove a proton from ethyne.



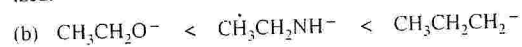
then



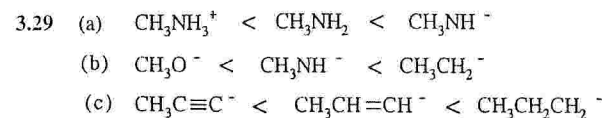
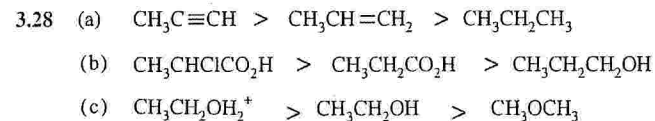
then



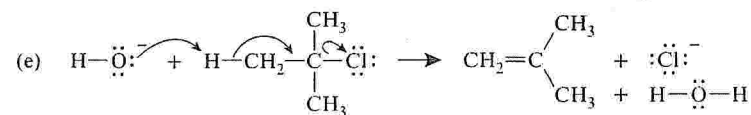
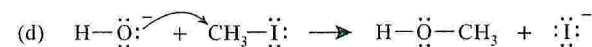
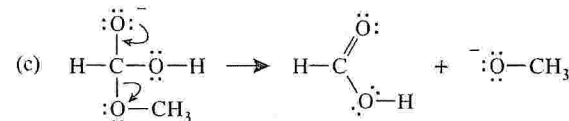
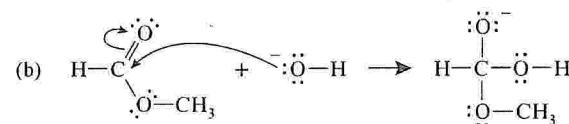
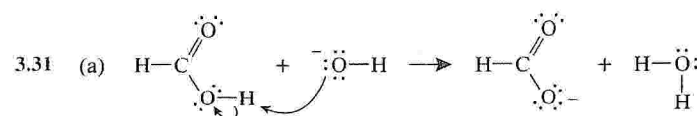
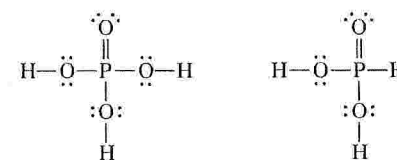
Oxygen is more electronegative than nitrogen, which is more electronegative than carbon. The O-H bond is most polarized, the N-H bond is next, and the C-H bond is least polarized.



The weaker the acid, the stronger the conjugate base.

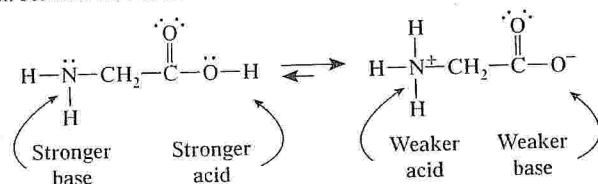


3.30 The acidic hydrogens must be attached to oxygen atoms. In  $\text{H}_3\text{PO}_3$ , one hydrogen is bonded to a phosphorus atom:





- 3.32 (a) Assume that the acidic and basic groups of glycine in its two forms have acidities and basicities similar to those of acetic acid and methylamine. Then consider the equilibrium between the two forms:



We see that the ionic form contains the groups that are the weaker acid and weaker base. The equilibrium, therefore, will favor this form.

- (b) The high melting point shows that the ionic structure better represents glycine.

- 3.33 (a) The second carboxyl group of malonic acid acts as an electron-withdrawing group and stabilizes the conjugate base formed (i.e.,  $\text{HO}_2\text{CCH}_2\text{CO}_2^-$ ) when malonic acid loses a proton. [Any factor that stabilizes the conjugate base of an acid always increases the strength of the acid (Section 3.10C).] An important factor here may be an entropy effect as explained in Section 3.9.

(b) When  $^-\text{O}_2\text{CCH}_2\text{CO}_2\text{H}$  loses a proton, it forms a dianion,  $^-\text{O}_2\text{CCH}_2\text{CO}_2^-$ . This dianion is destabilized by having two negative charges in close proximity.

- 3.34 HB is the stronger acid.

$$\begin{aligned} 3.35 \quad \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ \\ &= 6.3 \text{ kJ mol}^{-1} - (298 \text{ K})(0.0084 \text{ kJ mol}^{-1}\text{K}^{-1}) \\ &= 3.8 \text{ kJ mol}^{-1} \end{aligned}$$

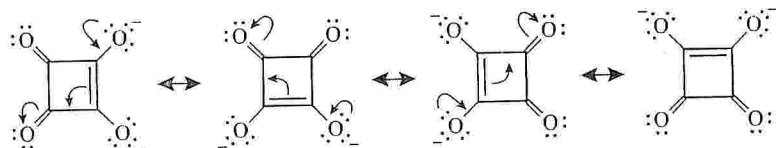
$$\log K_{\text{eq}} = \log K_a = -pK_a = -\frac{\Delta G^\circ}{2.303RT}$$

$$pK_a = \frac{\Delta G^\circ}{2.303RT}$$

$$pK_a = \frac{3.8 \text{ kJ mol}^{-1}}{(2.303)(0.008314 \text{ kJ mol}^{-1}\text{K}^{-1})(298 \text{ K})}$$

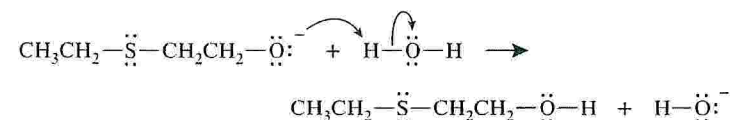
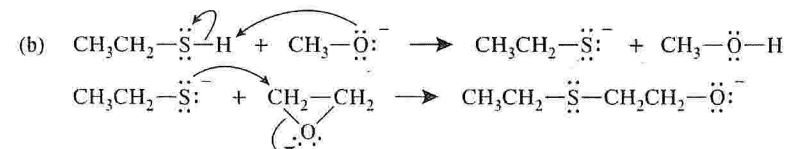
$$pK_a = 0.66$$

- 3.36 The dianion is a hybrid of the following resonance structures:



If we mentally fashion a hybrid of these structures, we see that each carbon-carbon bond is a single bond in three structures and a double bond in one. Each carbon-oxygen bond is a double bond in two structures and a single bond in two structures. Therefore, we would expect all of the carbon-carbon bonds to be equivalent and of the same length, and exactly the same can be said for the carbon-oxygen bonds.

- 3.37 (a) A is  $\text{CH}_3\text{CH}_2\text{S}^-$  B is  $\text{CH}_3\text{OH}$   
C is  $\text{CH}_3\text{CH}_2\text{SCH}_2\text{CH}_2\text{O}^-$  D is  $\text{CH}_3\text{CH}_2\text{SCH}_2\text{CH}_2\text{OH}$   
E is  $\text{OH}^-$

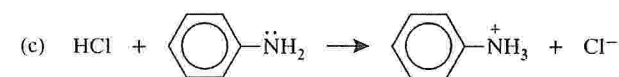


- 3.38 (a)  $\text{CH}_3(\text{CH}_2)_8\text{OD} + \text{CH}_3(\text{CH}_2)_8\text{Li} \rightarrow \text{CH}_3(\text{CH}_2)_8\text{O}^- \text{Li}^+ + \text{CH}_3(\text{CH}_2)_8\text{D}$

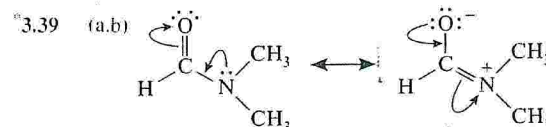
Hexane could be used as solvent. Liquid ammonia and ethanol could not because they would compete with  $\text{CH}_3(\text{CH}_2)_8\text{OD}$  and generate mostly non-deuterio-labelled  $\text{CH}_3(\text{CH}_2)_7\text{CH}_3$ .

- (b)  $\text{NH}_2^- + \text{CH}_3\text{C}\equiv\text{CH} \rightarrow \text{NH}_3 + \text{CH}_3\text{C}\equiv\text{C}^-$

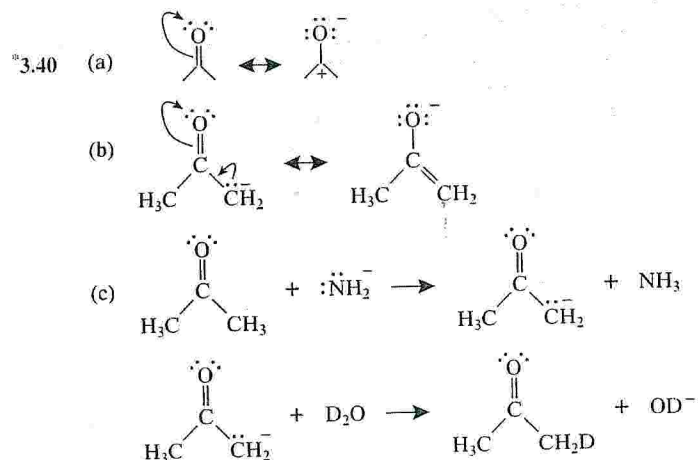
Hexane or liquid ammonia could be used; ethanol is too acidic and would lead to  $\text{CH}_3\text{CH}_2\text{O}^-$  (ethoxide ion) instead of the desired alkynide ion.



Hexane or ethanol could be used; liquid ammonia is too strong a base and would lead to  $\text{NH}_4^+$  instead of the desired anilinium ion.



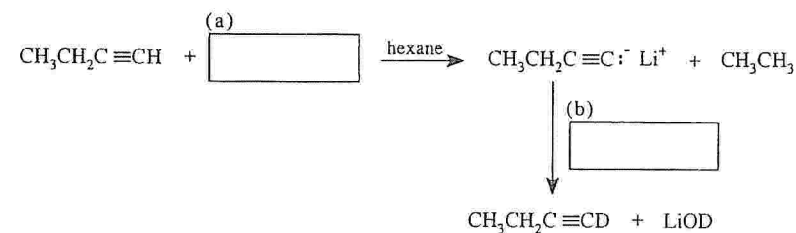
- (c) Since DMF does not bind with (solvate) anions, their electron density remains high and their size small, both of which make nucleophiles more reactive.



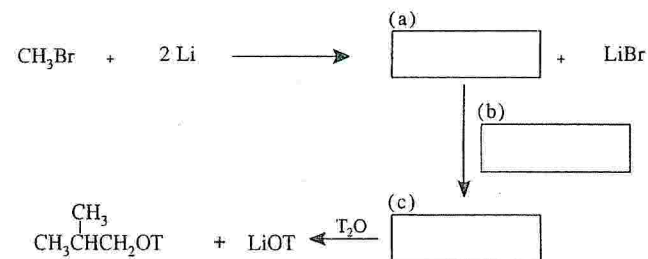
## QUIZ

- 3.1 Which of the following is the strongest acid?  
(a)  $\text{CH}_3\text{CH}_2\text{CO}_2\text{H}$  (b)  $\text{CH}_3\text{CH}_3$  (c)  $\text{CH}_3\text{CH}_2\text{OH}$  (d)  $\text{CH}_2=\text{CH}_2$
- 3.2 Which of the following is the strongest base?  
(a)  $\text{CH}_3\text{ONa}$  (b)  $\text{NaNH}_2$  (c)  $\text{CH}_3\text{CH}_2\text{Li}$  (d)  $\text{NaOH}$  (e)  $\text{CH}_3\text{CO}_2\text{Na}$
- 3.3 Dissolving  $\text{NaNH}_2$  in water will give:  
(a) A solution containing solvated  $\text{Na}^+$  and  $\text{NH}_2^-$  ions.  
(b) A solution containing solvated  $\text{Na}^+$  ions,  $\text{OH}^-$  ions, and  $\text{NH}_3$ .  
(c)  $\text{NH}_3$  and metallic Na.  
(d) Solvated  $\text{Na}^+$  ions and hydrogen gas.  
(e) None of the above.
- 3.4 Which base is strong enough to convert  $(\text{CH}_3)_3\text{COH}$  into  $(\text{CH}_3)_3\text{CONa}$  in a reaction that goes to completion?  
(a)  $\text{NaNH}_2$  (b)  $\text{CH}_3\text{CH}_2\text{Na}$  (c)  $\text{NaOH}$  (d)  $\text{CH}_3\text{CO}_2\text{Na}$   
(e) More than one of the above.
- 3.5 Which would be the strongest acid?  
(a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$  (b)  $\text{CH}_3\text{CH}_2\text{CHFCH}_2\text{CO}_2\text{H}$  (c)  $\text{CH}_3\text{CHFCH}_2\text{CO}_2\text{H}$   
(d)  $\text{CH}_2\text{FCH}_2\text{CH}_2\text{CO}_2\text{H}$  (e)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

- 3.6 Which would be the weakest base?  
(a)  $\text{CH}_3\text{CO}_2\text{Na}$  (b)  $\text{CF}_3\text{CO}_2\text{Na}$  (c)  $\text{CHF}_2\text{CO}_2\text{Na}$  (d)  $\text{CH}_2\text{FCO}_2\text{Na}$
- 3.7 What acid-base reaction (if any) would occur when  $\text{NaF}$  is dissolved in  $\text{H}_2\text{SO}_4$ ?
- 3.8 The  $\text{p}K_a$  of  $\text{CH}_3\text{NH}_3^+$  equals 10.6; the  $\text{p}K_a$  of  $(\text{CH}_3)_2\text{NH}_2^+$  equals 10.7. Which is the stronger base,  $\text{CH}_3\text{NH}_2$  or  $(\text{CH}_3)_2\text{NH}$ ?
- 3.9 Supply the missing reagents.



- 3.10 Supply the missing intermediates and reagents.



## 4

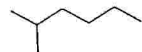
ALKANES: NOMENCLATURE,  
CONFORMATIONAL ANALYSIS, AND AN  
INTRODUCTION TO SYNTHESIS

## SOLUTIONS TO PROBLEMS

4.1



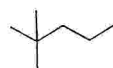
Heptane



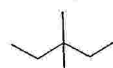
2-Methylhexane



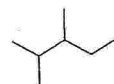
3-Methylhexane



2,2-Dimethylpentane



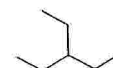
3,3-Dimethylpentane



2,3-Dimethylpentane



2,4-Dimethylpentane



3-Ethylpentane

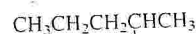


2,2,3-Trimethylbutane

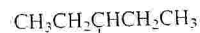
4.2



Pentyl



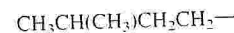
1-Methylbutyl



1-Ethylpropyl



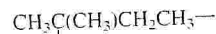
2-Methylbutyl



3-Methylbutyl



1,2-Dimethylpropyl



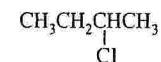
1,1-Dimethylpropyl

(b) See the answer to Problem 4.1 for the names of  $\text{C}_7\text{H}_{16}$  isomers.

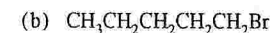
4.3



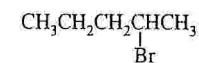
1-Chlorobutane



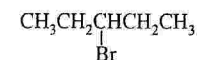
2-Chlorobutane



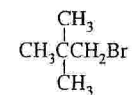
1-Bromopentane



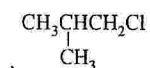
2-Bromopentane



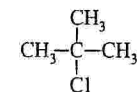
3-Bromopentane



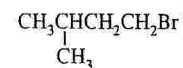
1-Bromo-2,2-dimethylpropane



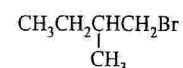
1-Chloro-2-methylpropane



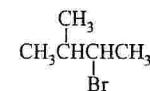
2-Chloro-2-methylpropane



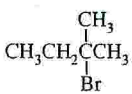
1-Bromo-3-methylbutane



1-Bromo-2-methylbutane

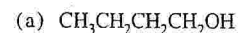


2-Bromo-3-methylbutane

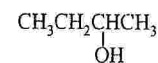


2-Bromo-2-methylbutane

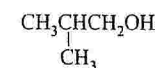
4.4



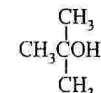
1-Butanol



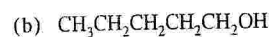
2-Butanol



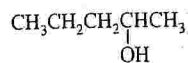
2-Methyl-1-propanol



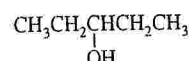
2-Methyl-2-propanol



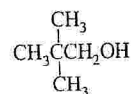
1-Pentanol



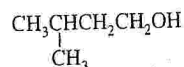
2-Pentanol



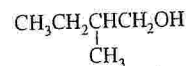
3-Pentanol



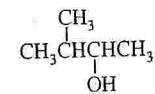
2,2-Dimethyl-1-propanol



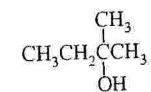
3-Methyl-1-butanol



2-Methyl-1-butanol



3-Methyl-2-butanol



2-Methyl-2-butanol

- 4.5 (a) 1-(1-Methylethyl)-2-(1,1-dimethylethyl)cyclopentane or 1-*tert*-butyl-2-isopropylcyclopentane  
 (b) 1-Methyl-2-(2-methylpropyl)cyclohexane or 1-isobutyl-2-methylcyclohexane  
 (c) Butylcyclohexane  
 (d) 1-Chloro-2,4-dimethylcyclohexane  
 (e) 2-Chlorocyclopentanol  
 (f) 3-(1,1-Dimethylethyl)cyclohexanol or 3-*tert*-butylcyclohexanol

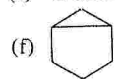
- 4.6 (a) 2-Chlorobicyclo[1.1.0]butane

- (b) Bicyclo[3.2.1]octane

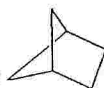
- (c) Bicyclo[2.1.1]hexane

- (d) 9-Chlorobicyclo[3.3.1]nonane

- (e) 2-Methylbicyclo[2.2.2]octane



Bicyclo[3.1.0]hexane or



bicyclo[2.1.1]hexane

- 4.7 (a) *trans*-3-Heptene

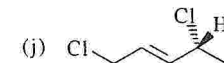
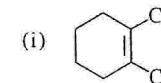
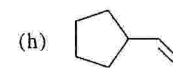
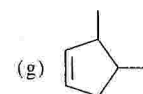
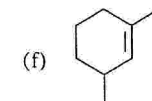
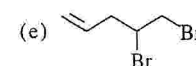
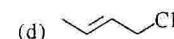
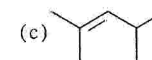
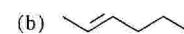
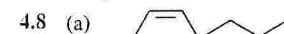
- (b) 2,5-Dimethyl-2-octene

- (c) 4-Ethyl-2-methyl-1-hexene

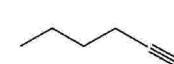
- (d) 3,5-Dimethylcyclohexene

- (e) 4-Methyl-4-penten-2-ol

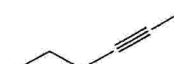
- (f) 2-Chloro-3-methyl-3-cyclohexen-1-ol



- 4.9



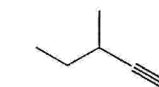
1-Hexyne



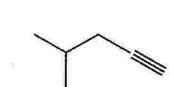
2-Hexyne



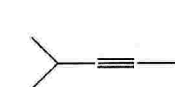
3-Hexyne



3-Methyl-1-pentyne

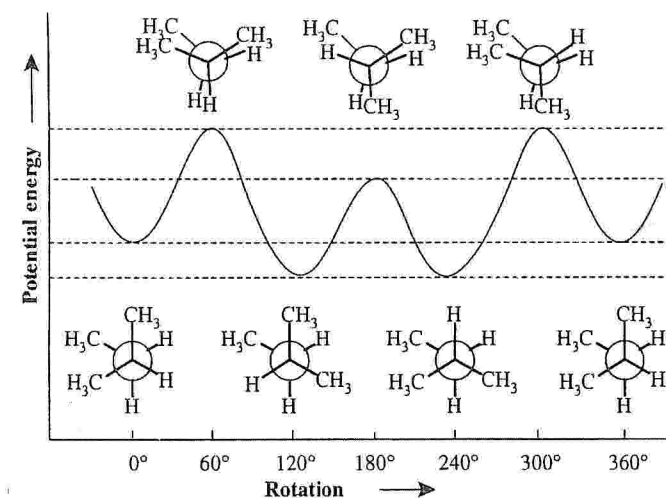


4-Methyl-1-pentyne



4-Methyl-2-pentyne

- 4.10





$$4.11 \quad \log K_{eq} = \frac{\Delta G^\circ}{-2.303RT} = \frac{-7600 \text{ J}}{(-2.303)(8.314 \text{ J K}^{-1})(298 \text{ K})} = 1.32$$

$$K_{eq} = 21.38$$

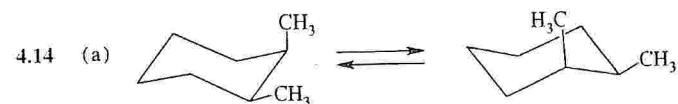
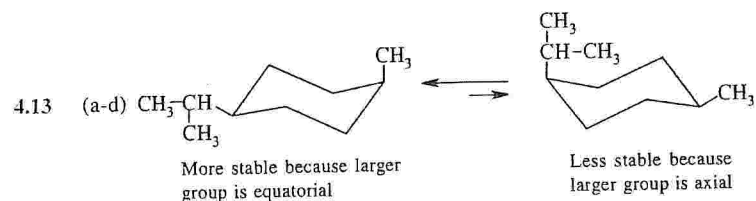
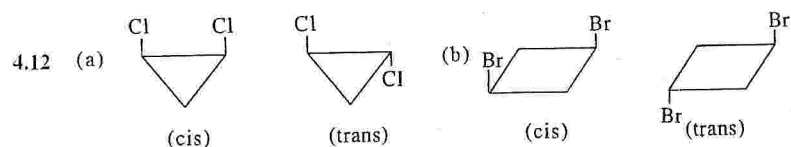
Let  $e$  = amount of equatorial form

and  $a$  = amount of axial form

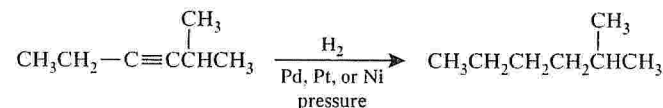
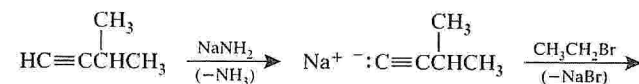
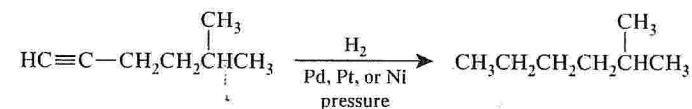
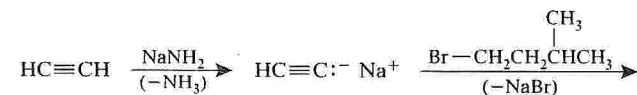
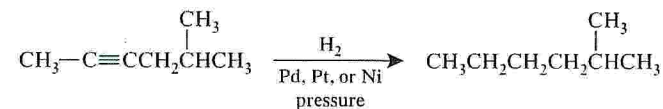
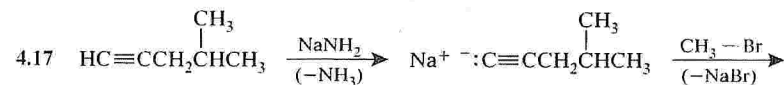
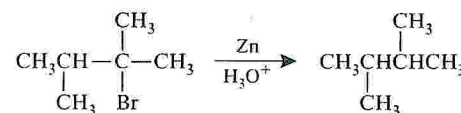
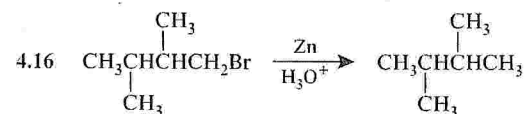
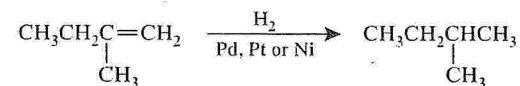
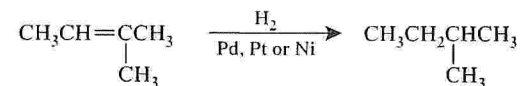
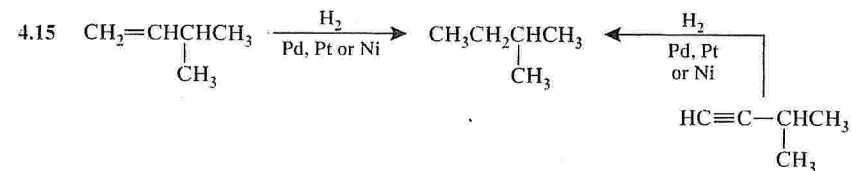
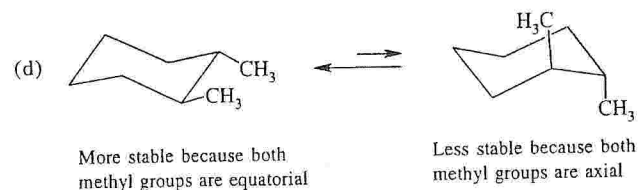
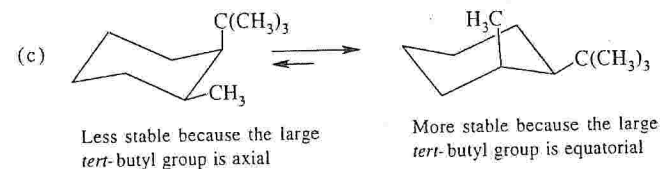
$$\text{then, } K_{eq} = \frac{e}{a} = 21.38$$

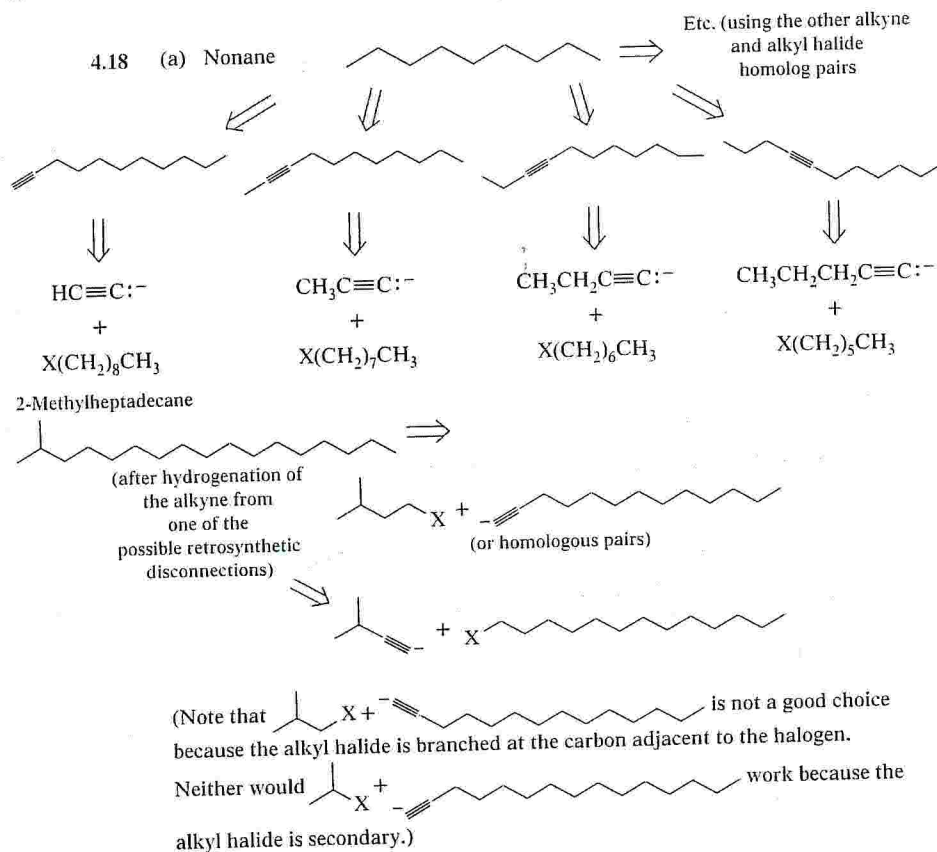
$$e = 21.38a$$

$$\%e = \frac{21.38a}{a + 21.38a} \times 100 = 95.5\%$$

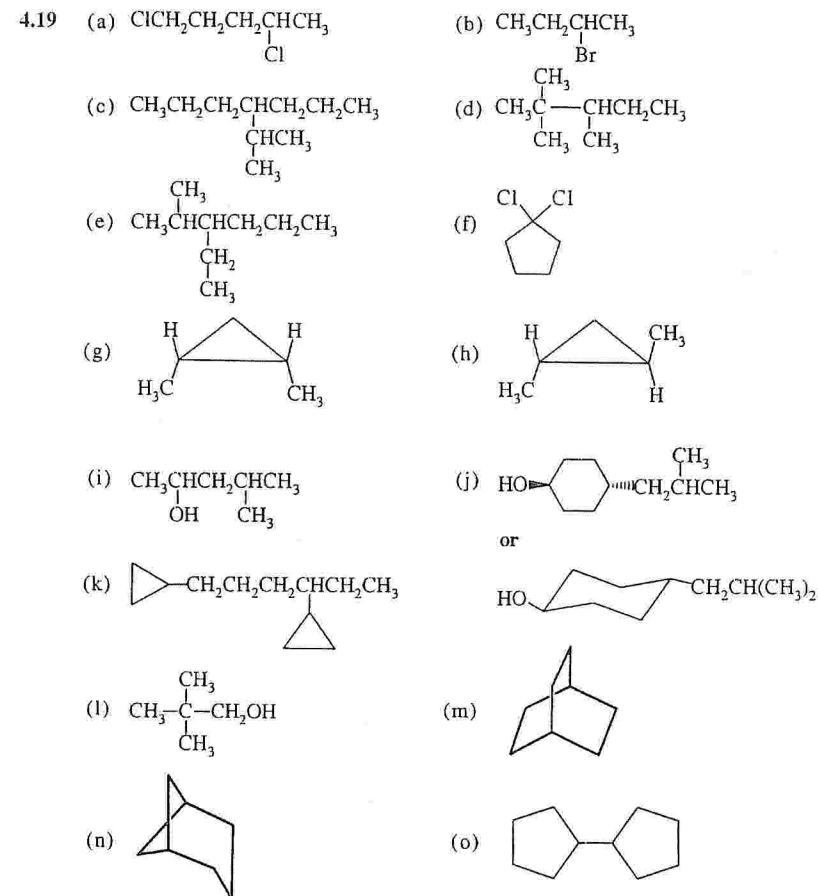
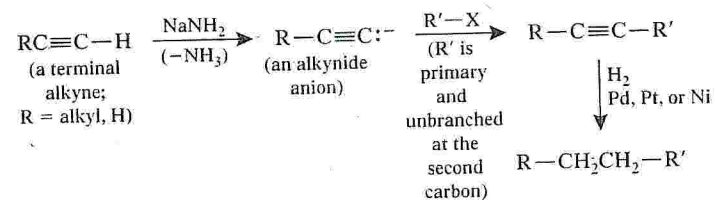


(b) Yes



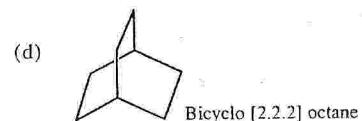
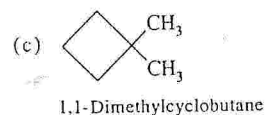
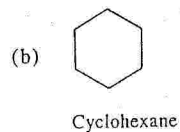
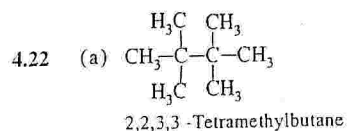


- (b) For any pair of reactants above that is a feasible retrosynthetic disconnection, the steps for the synthesis would be

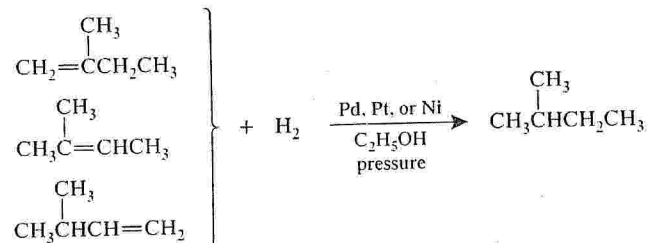


- 4.20 (a) 3,3,4-Trimethylhexane  
(b) 2,2-Dimethyl-1-butanol  
(c) 3,5,7-Trimethylnonane  
(d) 3-Methyl-4-heptanol  
(e) 2-Bromobicyclo[3.3.1]nonane  
(f) 2,5-Dibromo-4-ethyloctane  
(g) Cyclobutylcyclopentane  
(h) 7-Chlorobicyclo[2.2.1]heptane

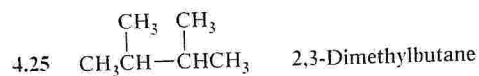
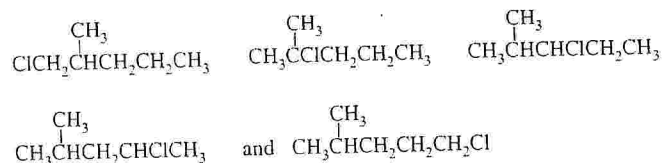
- 4.21 The two secondary carbon atoms in *sec*-butyl alcohol are equivalent; however, there are three five-carbon alcohols (pentyl alcohols) that contain a secondary carbon atom.



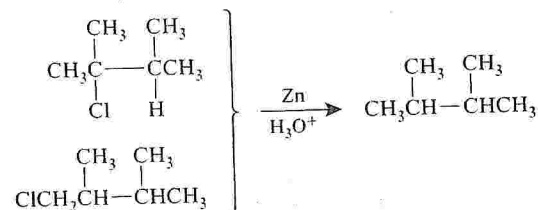
- 4.23 Each of the desired alkenes must have the same carbon skeleton as 2-methylbutane,  $\text{C}-\overset{\text{C}}{\text{C}}-\text{C}-\text{C}$ ; they are therefore



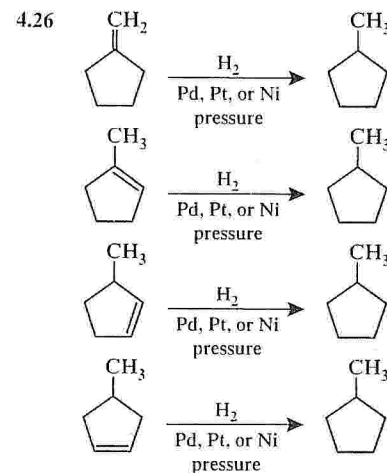
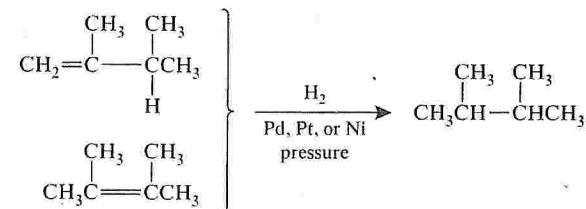
- 4.24 Only one isomer of  $\text{C}_6\text{H}_{13}\text{Cl}$  can be produced from five isomeric hexyl chlorides ( $\text{C}_6\text{H}_{13}\text{Cl}$ ). The alkane is 2-methylpentane,  $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$ . The five alkyl chlorides are



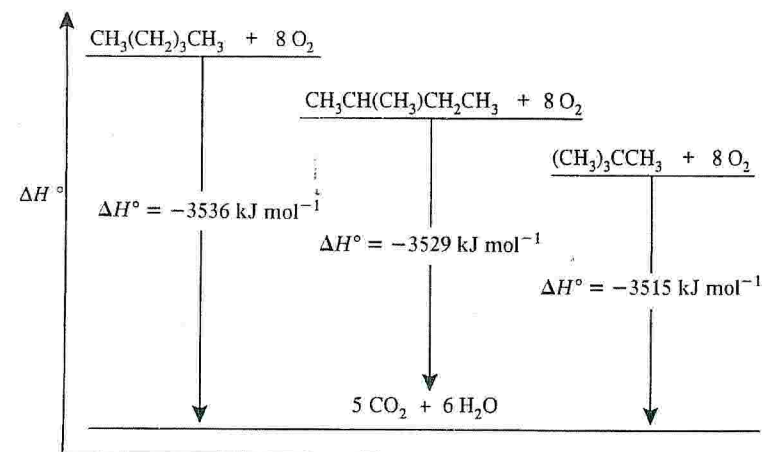
From two alkyl chlorides



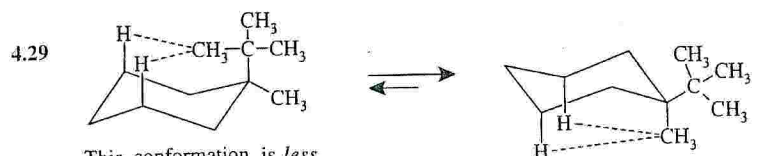
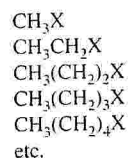
From two alkenes



- 4.27  $(\text{CH}_3)_3\text{CCH}_3$  is the most stable isomer (i.e., it is the isomer with the lowest potential energy) because it evolves the least amount of heat on a molar basis when subjected to complete combustion.

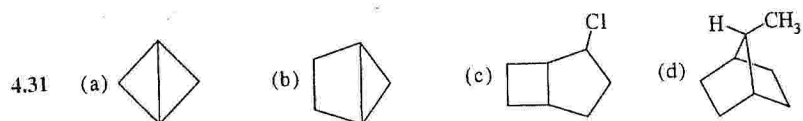
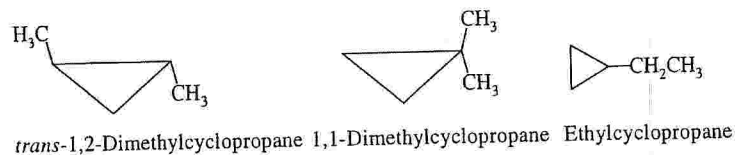
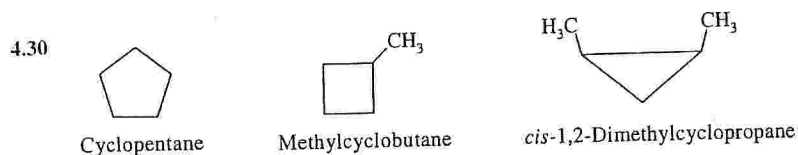


- 4.28 A homologous series is one in which each member of the series differs from the one preceding it by a constant amount, usually a  $\text{CH}_2$  group. A homologous series of alkyl halides would be the following:

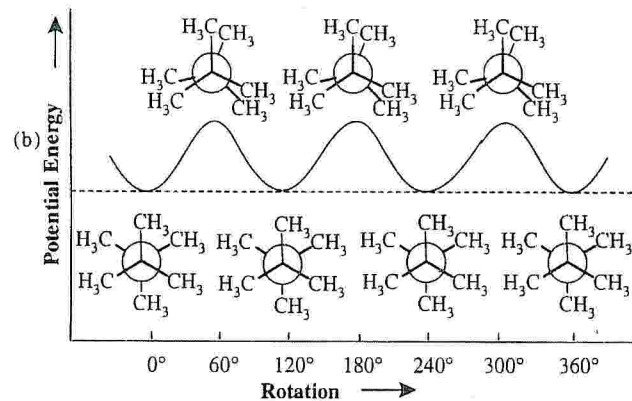
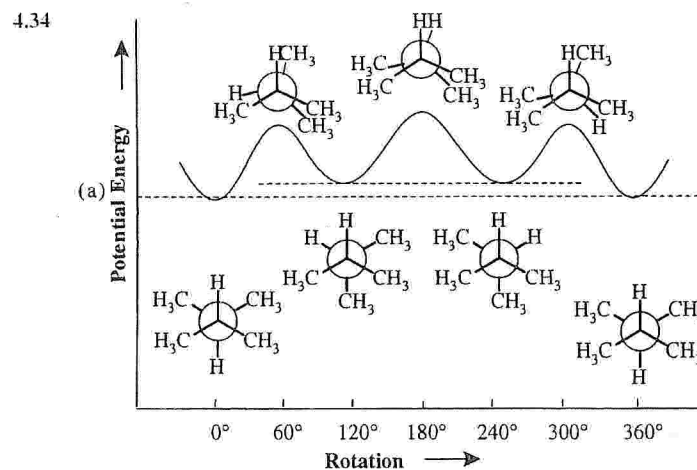
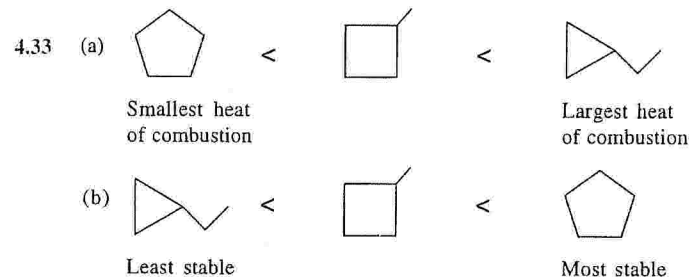


This conformation is *less stable* because 1,3-diaxial interactions with the large *tert*-butyl group cause considerable repulsion.

This conformation is *more stable* because 1,3-diaxial interactions with the smaller methyl group are less repulsive.

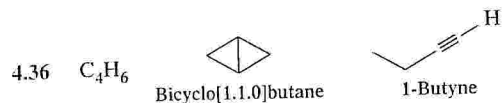


- 4.32  $S - A + 1 = N$   
For cubane,  $S = 12$  and  $A = 8$ . Thus  $12 - 8 + 1 = N$ ;  $N = 5$  rings in cubane.



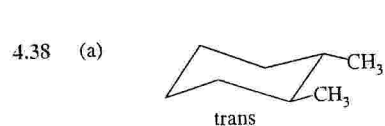
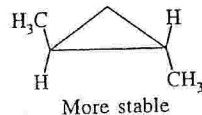
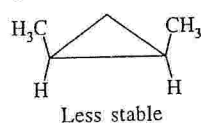


- 4.35 (a) Pentane would boil higher because its chain is unbranched. Chain-branching lowers the boiling point.  
 (b) Heptane would boil higher because it has the larger molecular weight and would, because of its larger surface area, have larger van der Waals attractions.  
 (c) 2-Chloropropane because it is more polar and because it has a larger molecular weight.  
 (d) 1-Propanol would boil higher because its molecules would be associated with each other through hydrogen-bond formation.  
 (e) Propanone ( $\text{CH}_3\text{COCH}_3$ ) would boil higher because its molecules are more polar.

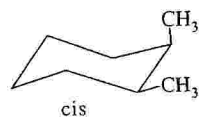


The IR stretch at  $\sim 2250\text{ cm}^{-1}$  for the alkyne  $\text{C}\equiv\text{C}$  bond distinguishes these two compounds.

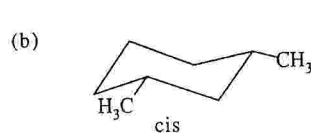
- 4.37 *trans*-1,2-Dimethylcyclopropane would be more stable because there is less crowding between its methyl groups.



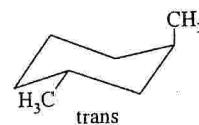
More stable because both methyl groups are equatorial in the most stable conformation



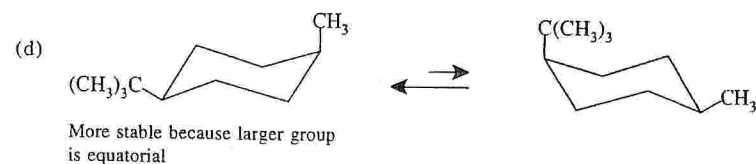
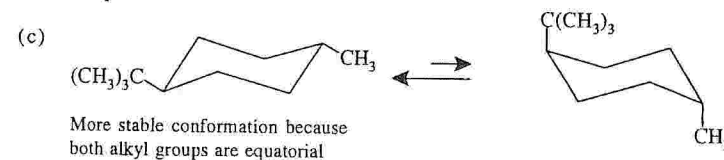
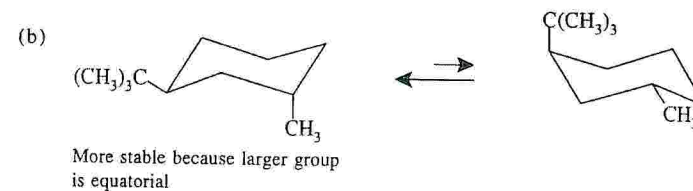
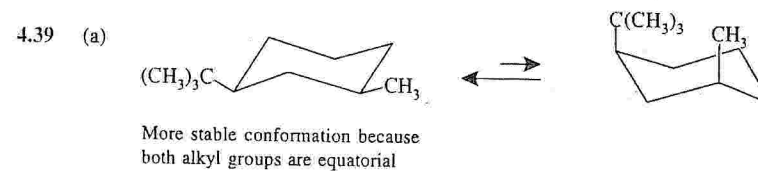
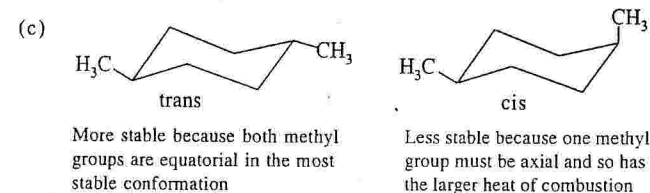
Less stable because one methyl group must be axial and so has the larger heat of combustion



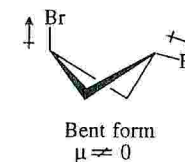
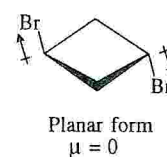
More stable because both methyl groups are equatorial in the most stable conformation



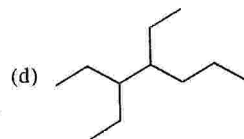
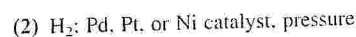
Less stable because one methyl group must be axial and so has the larger heat of combustion



- 4.40 If the cyclobutane ring were planar, the  $\text{C}-\text{Br}$  bond moments would exactly cancel in the *trans* isomer. The fact that *trans*-1,3-dibromocyclobutane has a dipole moment shows the ring is not planar.

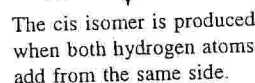


- (b) (1)  $\text{NaNH}_2$       (2)  $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

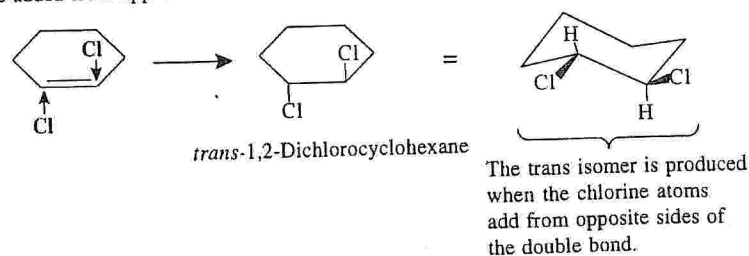


- (f)  $\text{X}-\text{CH}_2-\overset{\text{CH}_3}{\underset{\text{CH}_3}{\text{C}}}\text{CH}_3$

- (c) Since catalytic hydrogenation produces the cis isomer, both hydrogen atoms must have added from the same side of the double bond. (As we shall see in Section 7.14, this type of addition is called a syn addition.)



- (b) Since the product is the trans isomer, we can conclude that the chlorine atoms have added from opposite sides of the double bond.

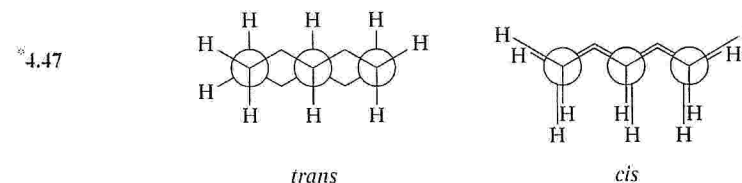


- 4.45 (a) More rules are needed (see Chapter 7) to indicate relative stereochemistry for these 1-bromo-2-chloro-1-fluoroethenes.  
 (b) Bicyclo[4.4.0]decane (or decalin)  
 (c) Bicyclo[4.4.0]dec-2-ene (or  $\Delta^1$ -octalin)  
 (d) Bicyclo[4.4.0]dec-1-ene (or  $\Delta^{1(\text{sat})}$ -octalin)

tive of naphthalene  that has had all of its five double bonds con-

Also, the symbol  $\Delta$  is one that has been used with common names to indicate the presence of a double bond at the position specified by the accompanying superscript number(s).

- Because if the configuration of stereocenters is changed, not all of the ring substituents can simultaneously be in the preferred equatorial position, as they are in glucose.


$$4.48 \quad \text{H}-\text{C}\equiv\text{C}-\text{C}\equiv\text{C}-\text{H} \xrightarrow[2 \text{ mol equiv. } \text{CH}_3(\text{CH}_2)_3\text{Br}]{2 \text{ mol equiv. } \text{LiNH}_2} \text{CH}_3(\text{CH}_2)_3-\text{C}\equiv\text{C}-\text{C}\equiv\text{C}-(\text{CH}_2)_3\text{CH}_3 \xrightarrow[\text{Pt catalyst}]{\text{H}_2} \text{CH}_3(\text{CH}_2)_{10}\text{CH}_3$$

## QUIZ

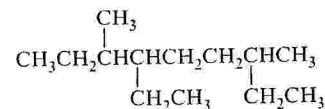
4.1 Consider the properties of the following compounds:

| NAME          | FORMULA                  | BOILING POINT (°C) | MOLECULAR WEIGHT |
|---------------|--------------------------|--------------------|------------------|
| Ethane        | $\text{CH}_3\text{CH}_3$ | -88.2              | 30               |
| Fluoromethane | $\text{CH}_3\text{F}$    | -78.6              | 34               |
| Methanol      | $\text{CH}_3\text{OH}$   | +64.7              | 32               |

Select the answer that explains why methanol boils so much higher than ethane or fluoromethane, even though they all have nearly equal molecular weights.

- (a) Ion-ion forces between molecules.
- (b) Weak dipole-dipole forces between molecules.
- (c) Hydrogen bonding between molecules.
- (d) van der Waals forces between molecules.
- (e) Covalent bonding between molecules.

4.2 Select the correct name of the compound whose structure is



- (a) 2,5-Diethyl-6-methyloctane
- (b) 4,7-Diethyl-3-methyloctane
- (c) 4-Ethyl-3,7-dimethylnonane
- (d) 6-Ethyl-3,7-dimethylnonane
- (e) More than one of the above

4.3 Select the correct name of the compound whose structure is  $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{Cl}$

- (a) Butyl chloride
- (b) Isobutyl chloride
- (c) *sec*-Butyl chloride
- (d) *tert*-Butyl chloride
- (e) More than one of the above

4.4 The structure shown in Problem 4.2 has:

- (a) 1°, 2°, and 3° carbon atoms
- (b) 1° and 2° carbon atoms only
- (c) 1° and 3° carbon atoms only
- (d) 2° and 3° carbon atoms only
- (e) None of the above

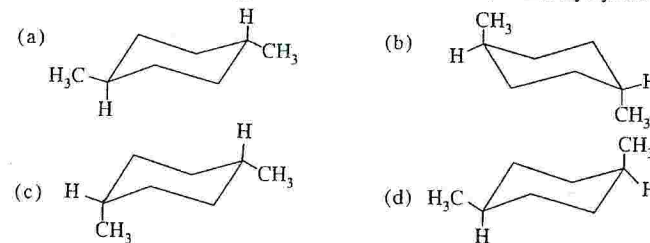
4.5 How many isomers are possible for  $\text{C}_3\text{H}_7\text{Br}$ ?

- (a) 1 (b) 2 (c) 3 (d) 4 (e) 5

4.6 Which isomer of 1,3-dimethylcyclohexane is more stable?

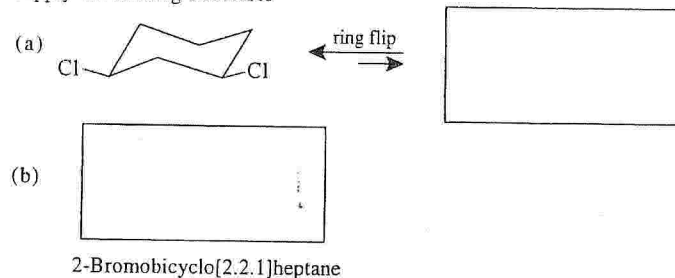
- (a) *cis* (b) *trans* (c) Both are equally stable
- (d) Impossible to tell

4.7 Which is the lowest energy conformation of *trans*-1,4-dimethylcyclohexane?

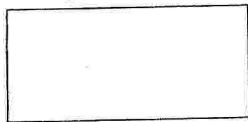


- (e) More than one of the above

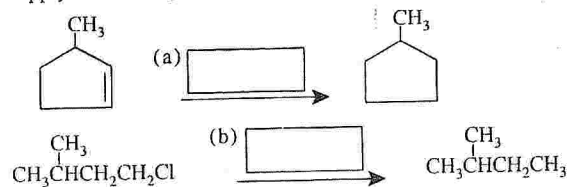
4.8 Supply the missing structures



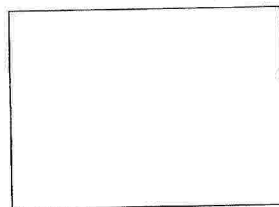
(c) Newman projection for a gauche form of 1,2-dibromoethane



4.9 Supply the missing reagents:



4.10 The most stable conformation of *trans*-1-isopropyl-3-methylcyclohexane:

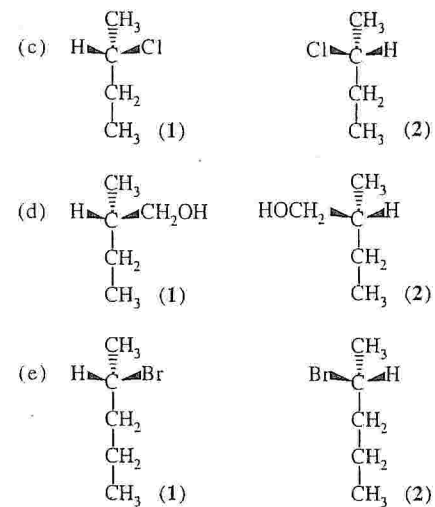


## 5

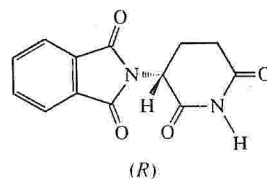
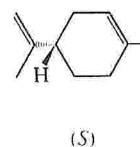
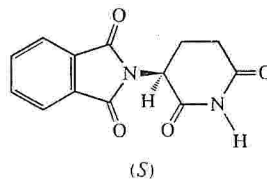
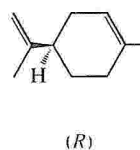
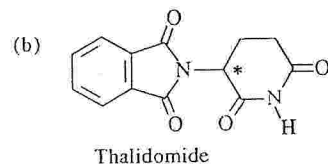
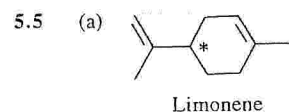
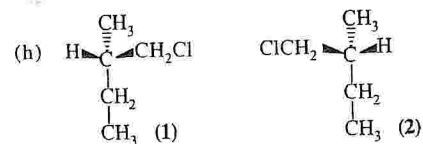
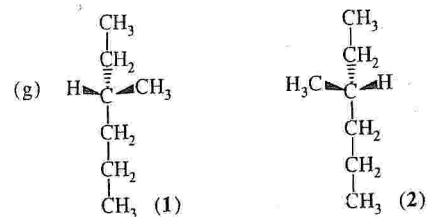
STEREOCHEMISTRY:  
CHIRAL MOLECULES

## SOLUTIONS TO PROBLEMS

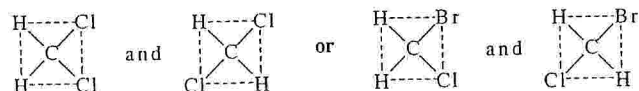
- 5.1 (a) Achiral (c) Chiral (e) Chiral (g) Chiral  
 (b) Achiral (d) Chiral (f) Chiral (h) Achiral
- 5.2 (a) Yes (b) No (c) No
- 5.3 (a) They are the same molecule. (b) They are enantiomers.
- 5.4 (a), (b), and (f) do not have stereocenters.



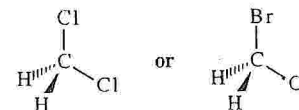




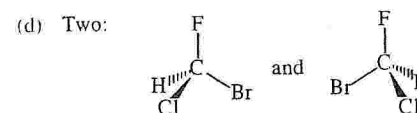
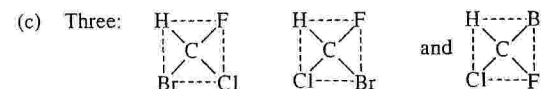
5.6 (a) Two in each instance.



(b) Only one in each instance.



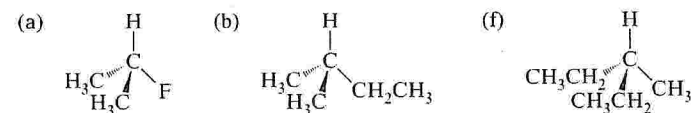
Any other tetrahedral arrangements will be superposable on one or the other of the above.



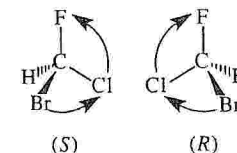
5.7 The following items possess a plane of symmetry, and are, therefore, achiral.

- (a) A screwdriver
- (b) A baseball bat (ignoring any writing on it)
- (h) A hammer

5.8 In each instance below, the plane defined by the page is a plane of symmetry.



5.9



5.10 (c) (1) is (S)  
(2) is (R)

(d) (1) is (S)  
(2) is (R)

(e) (1) is (S)  
(2) is (R)

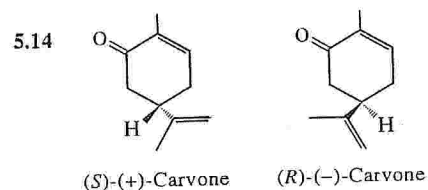
(g) (1) is (S)  
(2) is (R)

(h) (1) is (S)  
(2) is (R)

- 5.11 (a)  $-\text{Cl} > -\text{SH} > -\text{OH} > -\text{H}$   
 (b)  $-\text{CH}_2\text{Br} > -\text{CH}_2\text{Cl} > -\text{CH}_2\text{OH} > -\text{CH}_3$   
 (c)  $-\text{OH} > -\text{CHO} > -\text{CH}_3 > -\text{H}$   
 (d)  $-\text{C}(\text{CH}_3)_3 > -\text{CH}=\text{CH}_2 > -\text{CH}(\text{CH}_3)_2 > -\text{H}$   
 (e)  $-\text{OCH}_3 > -\text{N}(\text{CH}_3)_2 > -\text{CH}_3 > -\text{H}$

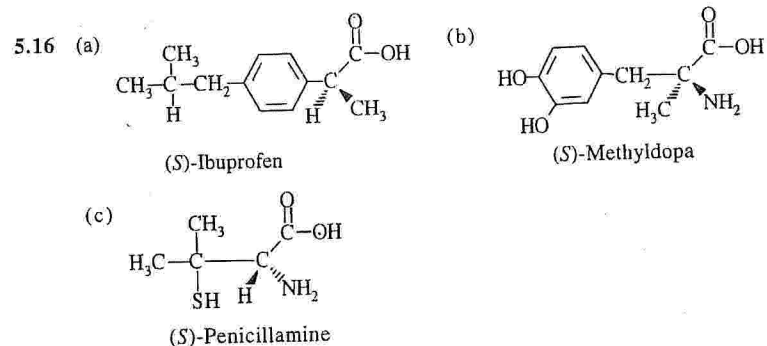
- 5.12 (a) (S) (b) (R) (c) (S)

- 5.13 (a) Enantiomers  
 (b) Two molecules of the same compound  
 (c) Enantiomers



5.15 (a) Enant. Excess =  $\frac{\text{observed rotation}}{\text{specific rotation of pure enantiomer}} \times 100$   
 $= \frac{+1.151^\circ}{+5.756^\circ} \times 100$   
 $= 20.00\%$

- (b) since the (R) enantiomer (see Section 5.7C) is +, the (R) enantiomer is present in excess.

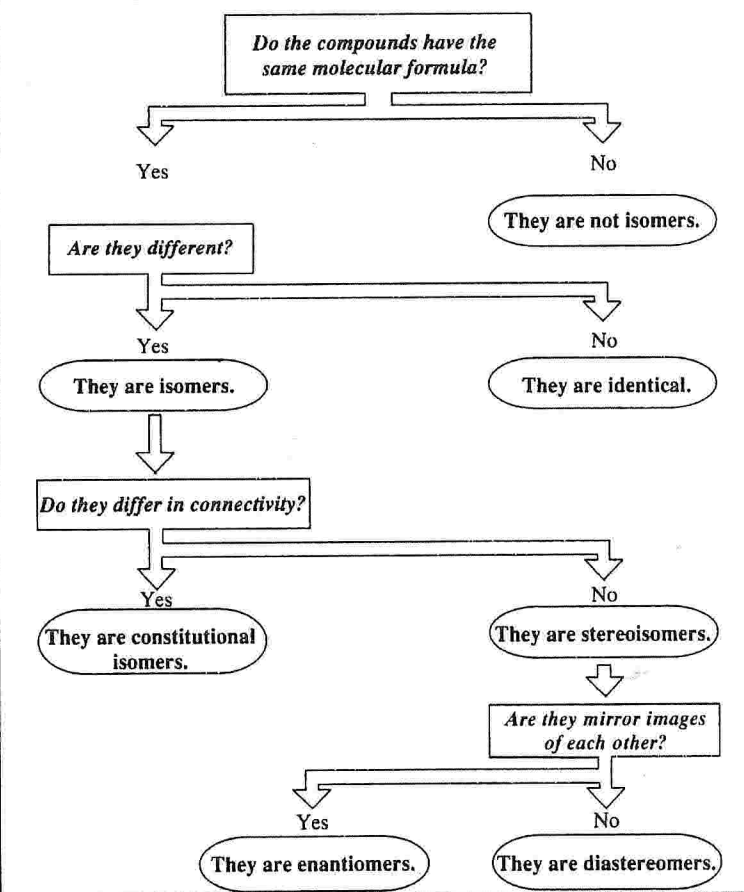


- 5.17 (a) Diastereomers.  
 (b) Diastereomers in each instance.  
 (c) No, diastereomers have different melting points.  
 (d) No, diastereomers have different boiling points.  
 (e) No, diastereomers have different vapor pressures.

## STUDY AID

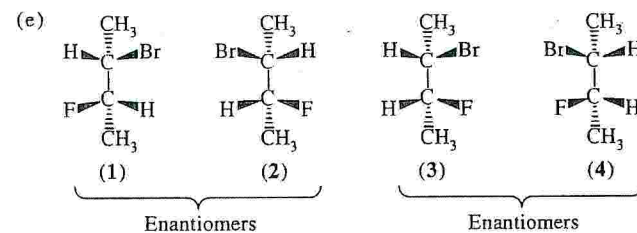
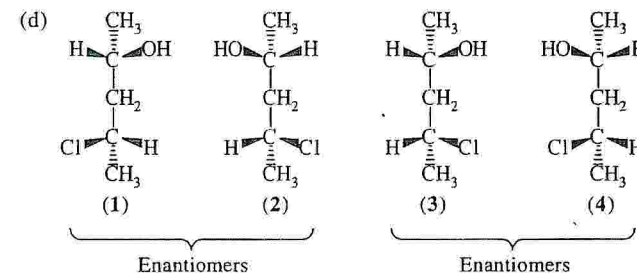
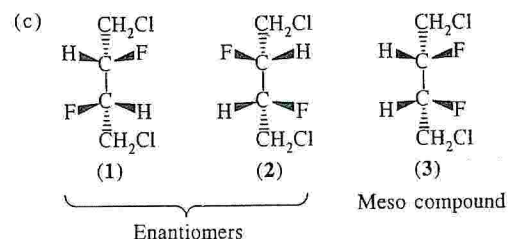
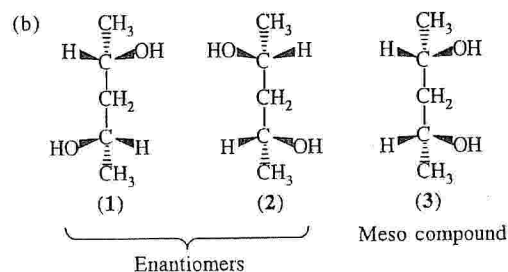
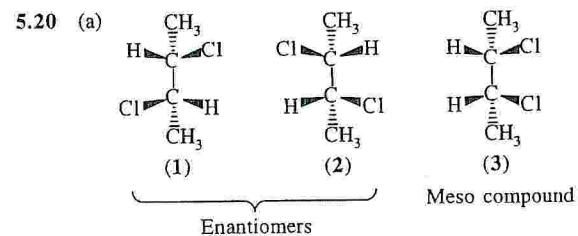
## An Approach to the Classification of Isomers

We can classify isomers by asking and answering a series of questions:



- 5.18 (a) It would be optically active.  
 (b) It would be optically active.  
 (c) No, because it is a meso compound.  
 (d) No, because it would be a racemic form.

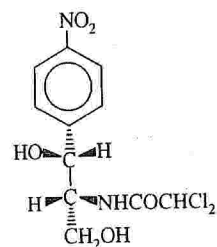
- 5.19 (a) Represents A  
 (b) Represents C  
 (c) Represents B



- 5.21 B is (2*S*,3*S*)-2,3-Dibromobutane  
 C is (2*R*,3*S*)-2,3-Dibromobutane

- 5.22 (a) (1) is (2*S*,3*S*)-2,3-Dichlorobutane  
 (2) is (2*R*,3*R*)-2,3-Dichlorobutane  
 (3) is (2*R*,3*S*)-2,3-Dichlorobutane  
 (b) (1) is (2*S*,4*S*)-2,4-Pentanediol  
 (2) is (2*R*,4*R*)-2,4-Pentanediol  
 (3) is (2*R*,4*S*)-2,4-Pentanediol  
 (c) (1) is (2*R*,3*R*)-1,4-Dichloro-2,3-difluorobutane  
 (2) is (2*S*,3*S*)-1,4-Dichloro-2,3-difluorobutane  
 (3) is (2*R*,3*S*)-1,4-Dichloro-2,3-difluorobutane  
 (d) (1) is (2*S*,4*S*)-4-Chloro-2-pentanol  
 (2) is (2*R*,4*R*)-4-Chloro-2-pentanol  
 (3) is (2*S*,4*R*)-4-Chloro-2-pentanol  
 (4) is (2*R*,4*S*)-4-Chloro-2-pentanol  
 (e) (1) is (2*S*,3*S*)-2-Bromo-3-fluorobutane  
 (2) is (2*R*,3*R*)-2-Bromo-3-fluorobutane  
 (3) is (2*S*,3*R*)-2-Bromo-3-fluorobutane  
 (4) is (2*R*,3*S*)-2-Bromo-3-fluorobutane

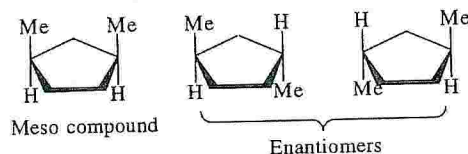
5.23



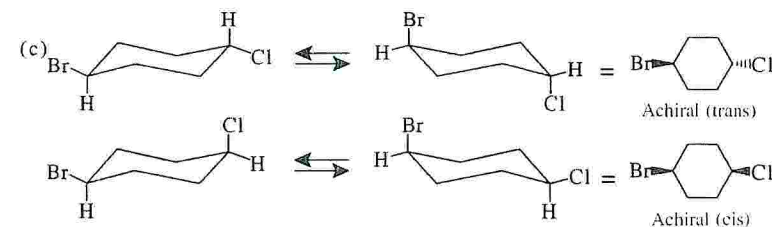
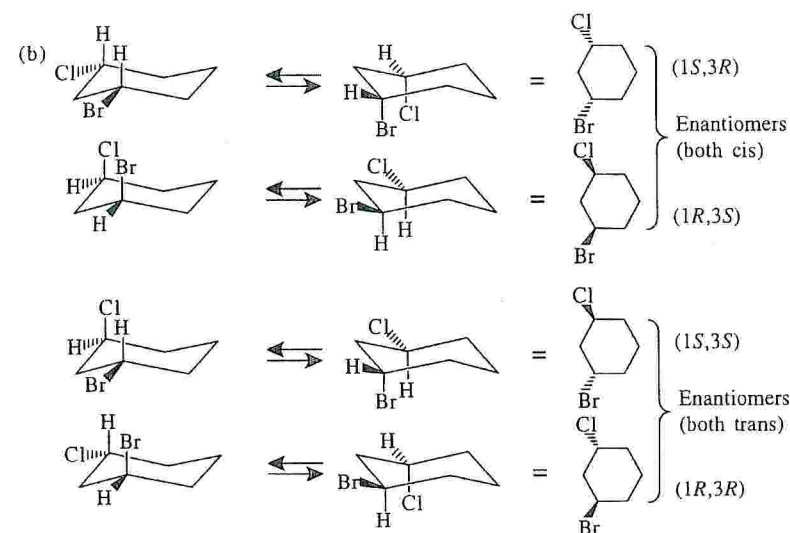
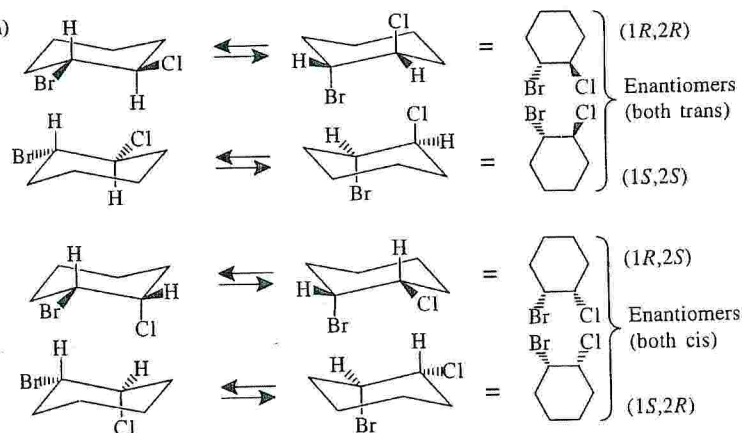
Chloramphenicol

- 5.24 (a) No (b) Yes (c) No (d) No (e) Diastereomers  
(f) Diastereomers

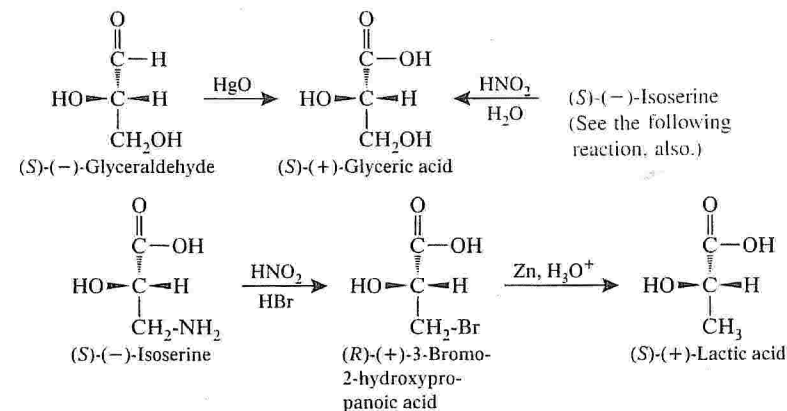
5.25



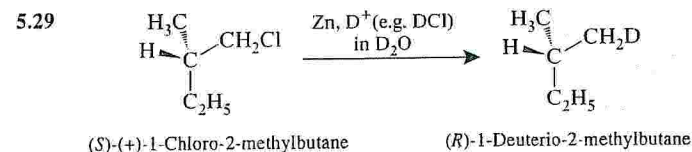
5.26 (a)

5.27 See Problem 5.26. The molecules in (c) are achiral, so they have no (*R-S*) designation.

5.28







5.30 (a), (b), (f) and (g) only

5.31 (a) Seven.

(b) (*R*)- and (*S*)-3-methylhexane and (*R*)- and (*S*)-2,3-dimethylpentane.

5.32 (a) and (b)

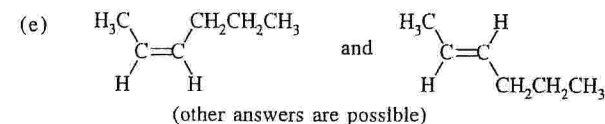
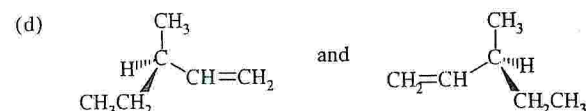
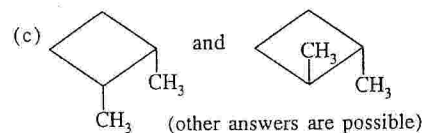
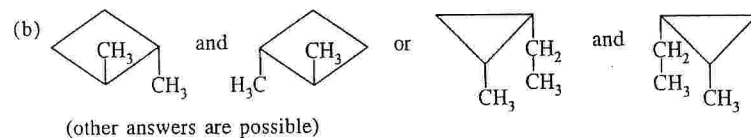
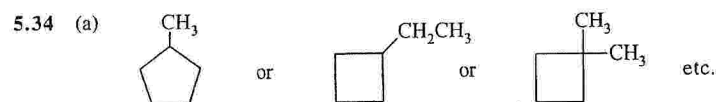


(c) Four

(d) Because a trans arrangement of the one carbon bridge is structurally impossible. Such a molecule would have too much strain.

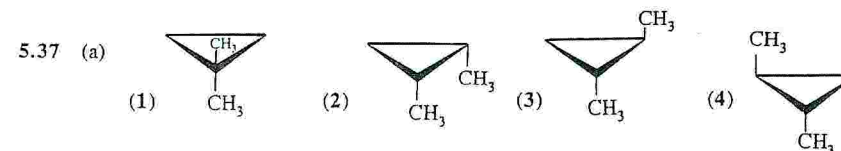
5.33 (a) **A** is (*R,S*)-2,3-dichlorobutane; **B** is (*S,S*)-2,3-dichlorobutane; **C** is (*R,R*)-2,3-dichlorobutane.

(b) A

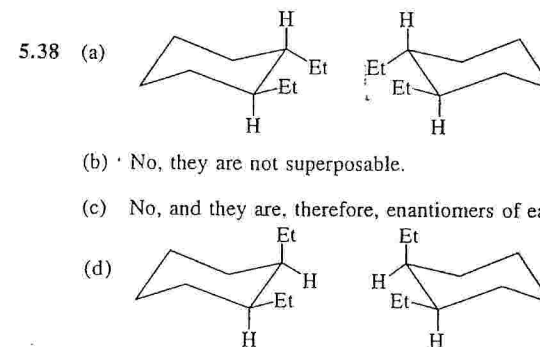


- 5.35
- |                            |                                                          |
|----------------------------|----------------------------------------------------------|
| (a) Same                   | (j) Enantiomers that are interconvertible by a ring flip |
| (b) Enantiomers            | (k) Diastereomers                                        |
| (c) Diastereomers          | (l) Same                                                 |
| (d) Same                   | (m) Diastereomers                                        |
| (e) Same                   | (n) Constitutional isomers                               |
| (f) Constitutional isomers | (o) Diastereomers                                        |
| (g) Diastereomers          | (p) Same                                                 |
| (h) Enantiomers            | (q) Same                                                 |
| (i) Same                   |                                                          |

5.36 All of these molecules are expected to be planar. Their stereochemistry is identical to that of the corresponding chloroethenes. (a) can exist as cis and trans isomers. Only one compound exists in the case of (b) and (c).

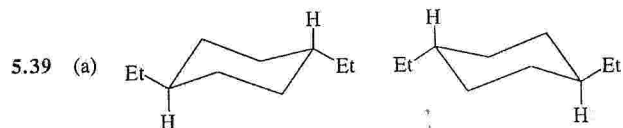


- (b) (3) and (4) are chiral and are enantiomers of each other.
- (c) Three fractions: a fraction containing (1), a fraction containing (2), and a fraction containing (3) and (4) [because, being enantiomers, (3) and (4) would have the same vapor pressure].
- (d) None



(e) No, they are not superposable.

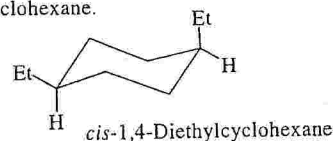
(f) Yes, and they are, therefore, just different conformations of the same molecule.



(b) Yes, and therefore *trans*-1,4-diethylcyclohexane is achiral.

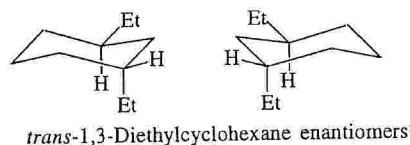
(c) No, they are different orientations of the same molecule.

(d) Yes, *cis*-1,4-diethylcyclohexane is a stereoisomer (a diastereomer) of *trans*-1,4-diethylcyclohexane.

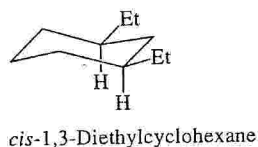


(e) No, it, too, is superposable on its mirror image. (Notice, too, that the plane of the page constitutes a plane of symmetry for both *cis*-1,4-diethylcyclohexane and for *trans*-1,4-diethylcyclohexane as we have drawn them.)

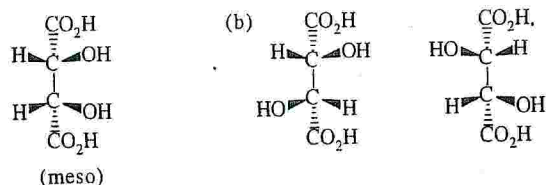
5.40 *trans*-1,3-Diethylcyclohexane can exist in the following enantiomeric forms.



*cis*-1,3-Diethylcyclohexane consists of achiral molecules because they have a plane of symmetry. [The plane of the page (below) is a plane of symmetry.]



\*5.41 (a) Since it is optically active and not resolvable, it must be the *meso* form:



(c) No (d) A racemic modification

\*5.42 (a)  $[\alpha]_D = \frac{-30^\circ}{(0.10 \text{ g/mL})(1.0 \text{ dm})} = -300^\circ$

(b)  $[\alpha]_D = \frac{+165^\circ}{(0.05 \text{ g/mL})(1.0 \text{ dm})} = +3300^\circ$

The two rotation values can be explained by recognizing that this is a powerfully optically active substance and that the first reading, assumed to be  $-30^\circ$ , was really  $+330^\circ$ . Making this change the  $[\alpha]_D$  becomes  $+3300^\circ$  in both cases.

(c) No, the apparent  $0^\circ$  rotation could actually be  $+$  or  $-360^\circ$  (or an integral multiple of these values).

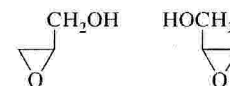
\*5.43 Yes, it could be a *meso* form or an enantiomer whose stereocenters, by rare coincidence, happen to cancel each others activities.

\*5.44 A compound  $C_3H_6O_2$  has an index of hydrogen deficiency of 1. Thus, it could possess a carbon-carbon double bond, a carbon-oxygen double bond, or a ring.

The IR spectral data rule out a carbonyl group but indicate the presence of an  $-OH$  group.

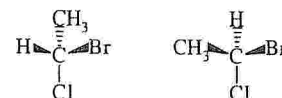
No stable structure having molecular formula  $C_3H_6O_2$  with a  $C=C$  bond can exist in stereoisomeric forms and 1,2-cyclopropanediol can exist in three stereoisomeric forms.

Only ethylene oxide (oxirane) derivatives are possible for Y:



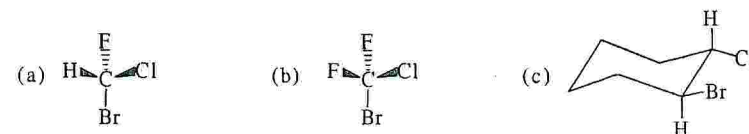
## QUIZ

5.1 Describe the relationship between the two structures shown.



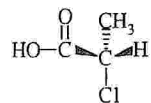
- (a) Enantiomers (b) Diastereomers (c) Constitutional isomers  
(d) Conformations (e) Two molecules of the same compound

5.2 Which of the following molecule(s) possess(es) a plane of symmetry?



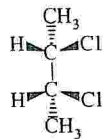
- (d) More than one of these (e) None of these

- 5.3 Give the (*R*-*S*) designation of the structure shown.



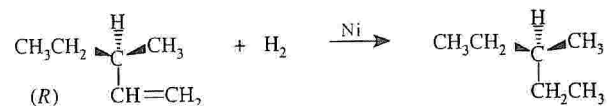
- (a) (*R*)      (b) (*S*)      (c) Neither, because this molecule has no stereocenter  
(d) Impossible to tell

- 5.4 Select the words that best describe the following structure:



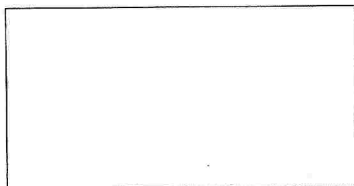
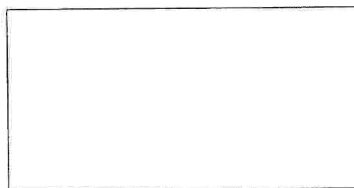
- (a) Chiral      (b) Meso form      (c) Achiral      (d) Has a plane of symmetry  
(e) More than one of these

- 5.5 Select the words that best describe what happens to the optical rotation of the alkene shown when it is hydrogenated to the alkane according to the following equation:

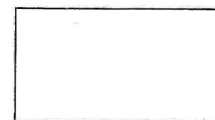


- (a) Increases      (b) Drops to zero      (c) Changes sign  
(d) Stays the same      (e) Impossible to predict

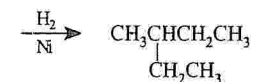
- 5.6 There are two compounds with the formula  $C_7H_{16}$  that are capable of existing as enantiomers. Write three-dimensional formulas for the (*S*) isomer of each.



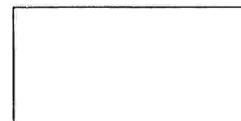
- 5.7 Compound A is optically active and is the (*S*) isomer.



A



- 5.8 Compound B is a hydrocarbon with the minimum number of carbon atoms necessary for it to possess a stereocenter and, as well, alternative stereochemistries about a double bond.

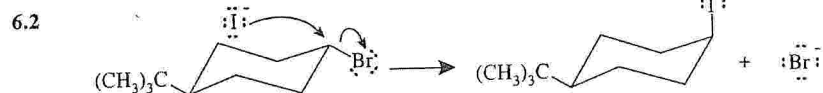
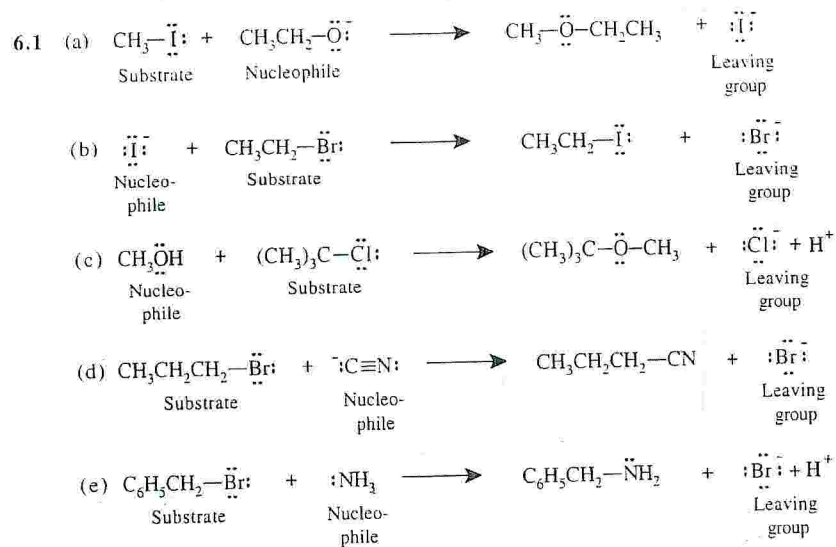


B

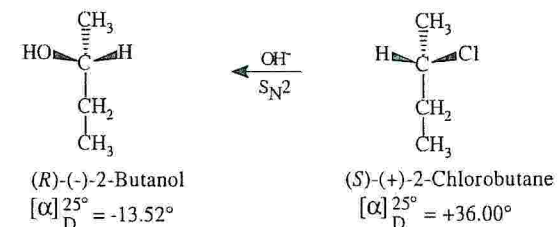
# 6

## IONIC REACTIONS— NUCLEOPHILIC SUBSTITUTION AND ELIMINATION REACTIONS OF ALKYL HALIDES

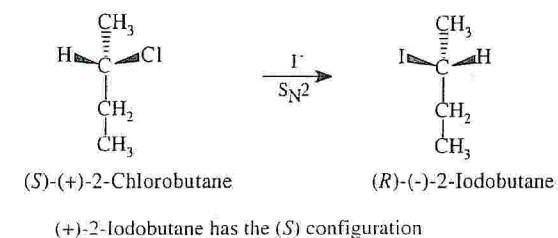
### SOLUTIONS TO PROBLEMS



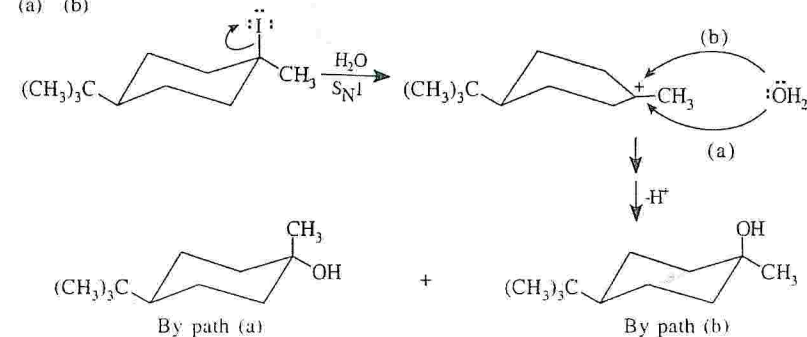
6.3 (a) We know that when a secondary alkyl halide reacts with hydroxide ion by substitution, the reaction occurs with *inversion of configuration* because the reaction is  $\text{S}_{\text{N}}2$ . If we know that the configuration of (–)-2-butanol (from Section 5.7C) is that shown here, then we can conclude that (+)-2-chlorobutane has the opposite configuration.



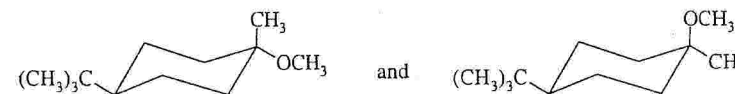
(b) Again the reaction is  $\text{S}_{\text{N}}2$ . Because we now know the configuration of (+)-2-chlorobutane to be (S) [cf., part (a)], we can conclude that the configuration of (–)-2-iodobutane is (R).



6.4 (a) (b)



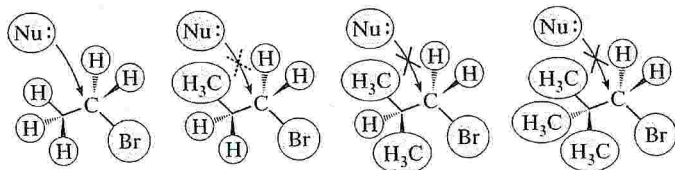
6.5





6.6 (a) Being primary halides, the reactions are most likely to be  $S_N2$ , with the nucleophile in each instance being a molecule of the solvent (i.e., a molecule of ethanol).

(b) Steric hindrance is provided by the substituent or substituents on the carbon  $\beta$  to the carbon bearing the leaving group. With each addition of a methyl group at the  $\beta$  carbon (below), the number of pathways open to the attacking nucleophile becomes fewer.



6.7 **Protic solvents** are those that have an H bonded to an oxygen or nitrogen (or to another strongly electronegative atom). Therefore, the protic solvents are formic acid,  $\text{HCOOH}$ ;

formamide,  $\text{HCNH}_2$ ; ammonia,  $\text{NH}_3$ ; and ethylene glycol,  $\text{HOCH}_2\text{CH}_2\text{OH}$

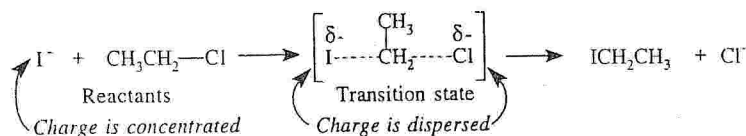
**Aprotic solvents** lack an H bonded to a strongly electronegative element. Aprotic solvents in this list are acetone,  $\text{CH}_3\text{C}(=\text{O})\text{CH}_3$ ; acetonitrile,  $\text{CH}_3\text{C}\equiv\text{N}$ ; sulfur dioxide,  $\text{SO}_2$ ; and trimethylamine,  $\text{N}(\text{CH}_3)_3$ .

6.8 The reaction is an  $S_N2$  reaction. In the polar aprotic solvent (DMF), the nucleophile ( $\text{CN}^-$ ) will be relatively unencumbered by solvent molecules, and, therefore, it will be more reactive than in ethanol. As a result, the reaction will occur faster in *N,N*-dimethylformamide.

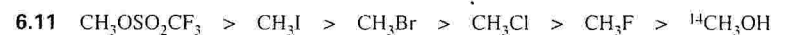
- 6.9 (a)  $\text{CH}_3\text{O}^-$   
 (b)  $\text{H}_2\text{S}$   
 (c)  $(\text{CH}_3)_3\text{P}$

6.10 (a) Increasing the percentage of water in the mixture increases the polarity of the solvent. (Water is more polar than methanol.) Increasing the polarity of the solvent increases the rate of the solvolysis because separated charges develop in the transition state. The more polar the solvent, the more the transition state is stabilized (Section 6.14D).

(b) In an  $S_N2$  reaction of this type, the charge becomes dispersed in the transition state:

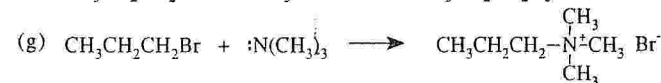
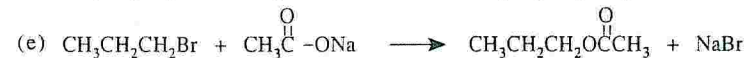
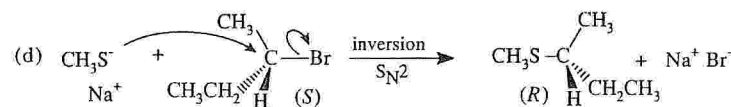
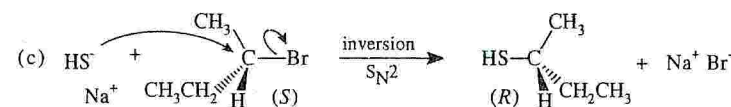
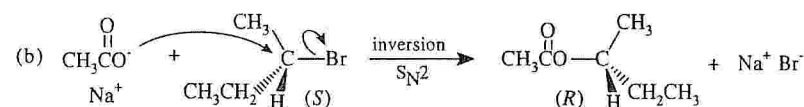
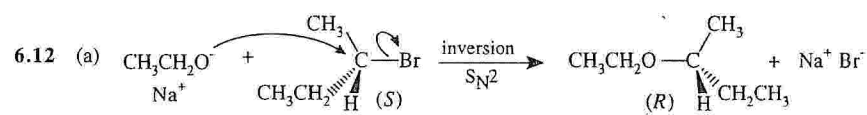


Increasing the polarity of the solvent increases the stabilization of the reactant  $\text{I}^-$  more than the stabilization of the transition state, and thereby increases the free energy of activation, thus decreasing the rate of reaction.



(Most reactive)

(Least reactive)



6.14 (a) 1-Bromopropane would react more rapidly because, being a primary halide, it is less hindered.



6.19 The better yield will be obtained by using the secondary halide, 1-bromo-1-phenylethane, because the desired reaction is E2. Using the primary halide will result in substantial  $S_N2$  reaction as well, producing the alcohol instead of the desired alkene.

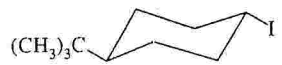
6.20 Reaction (2) would give the better yield because the desired reaction is an  $S_N2$  reaction, and the substrate is a methyl halide. Use of reaction (1) would, because the substrate is a secondary halide, result in considerable elimination by an E2 pathway.

6.21 (a) The major product would be  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$  (by an  $S_N2$  mechanism) because the substrate is primary and the nucleophile-base is not hindered. Some  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$  would be produced by an E2 mechanism.

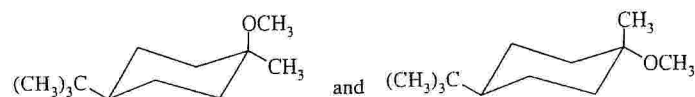
(b) The major product would be  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$  (by an E2 mechanism), even though the substrate is primary because the base is a hindered strong base. Some  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OC}(\text{CH}_3)_3$  would be produced by an  $S_N2$  mechanism.

(c) For all practical purposes,  $(\text{CH}_3)_2\text{C}=\text{CH}_2$  (by an E2 mechanism) would be the only product because the substrate is tertiary and the base is strong.

(d) Same answer as (c) above.

(e)  (formed by an  $S_N2$  mechanism) would, for all practical purposes, be the only product. Iodide ion is a very weak base and a good nucleophile.

(f) Because the substrate is tertiary and the only nucleophile is the solvent, mechanism is  $S_N1$ . The two products that follow would be formed.

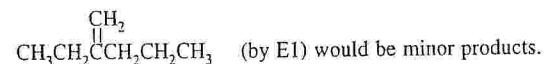
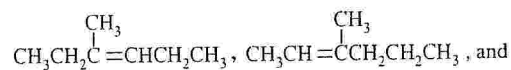


(g)  $\text{CH}_3\text{CH}=\text{CHCH}_2\text{CH}_3$  (by an E2 mechanism) would be the major product because the substrate is secondary and the base/nucleophile is a strong base. Some of the ether,  $\text{CH}_3\text{CH}_2\text{CH}(\text{OCH}_3)\text{CH}_2\text{CH}_3$ , would be formed by an  $S_N2$  pathway.

(h) The major product would be  $\text{CH}_3\text{CH}_2\text{CH}(\text{O}_2\text{CCH}_3)\text{CH}_2\text{CH}_3$  (by an  $S_N2$  mechanism) because the acetate ion is a weak base. Some  $\text{CH}_3\text{CH}=\text{CHCH}_2\text{CH}_2\text{CH}_3$  might be formed by an E2 pathway.

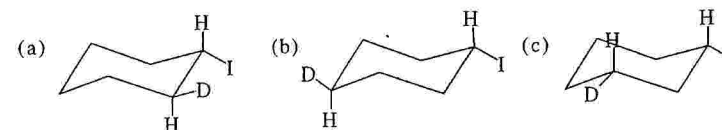
(i)  $\text{CH}_3\text{CH}=\text{CHCH}_3$  and  $\text{CH}_2=\text{CHCH}_2\text{CH}_3$  (by E2) would be major products, and  $(S)\text{-CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$  (by  $S_N2$ ) would be the minor product.

(j)  $(\pm)\text{-CH}_3\text{CH}_2\text{C}(\text{CH}_3)(\text{OCH}_3)\text{CH}_2\text{CH}_3$  (by  $S_N1$ ) would be the major product.

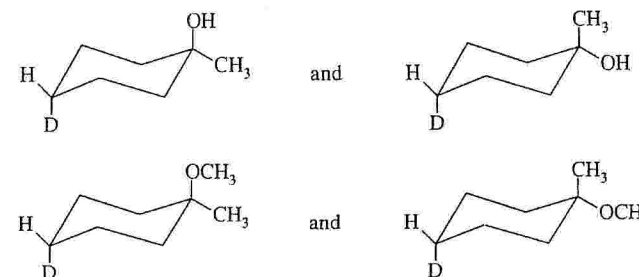


(k)  $(R)\text{-CH}_3\text{CHIC}_6\text{H}_{13}$  (by  $S_N2$ ) would be the only product.

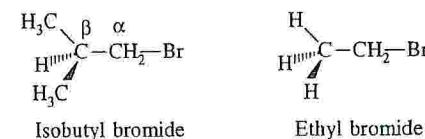
6.22 (a), (b), and (c) are all  $S_N2$  reactions and, therefore, proceed with inversion of configuration. The products are



(d) is an  $S_N1$  reaction. The carbocation that forms can react with either nucleophile ( $\text{H}_2\text{O}$  or  $\text{CH}_3\text{OH}$ ) from either the top or bottom side of the molecule. Four substitution products (below) would be obtained. (Considerable elimination by an E1 path would also occur.)



6.23 Isobutyl bromide is more sterically hindered than ethyl bromide because of the methyl groups on the  $\beta$  carbon atom.



This steric hindrance causes isobutyl bromide to react more slowly in  $S_N2$  reactions and to give relatively more elimination (by an E2 path) when a strong base is used.

6.24 (a)  $S_N2$  because the substrate is a  $1^\circ$  halide.

$$\begin{aligned} \text{(b) Rate} &= k [\text{CH}_3\text{CH}_2\text{Cl}] [\text{I}^-] \\ &= 5 \times 10^{-5} \text{ L mol}^{-1} \text{ s}^{-1} \times 0.1 \text{ mol L}^{-1} \times 0.1 \text{ mol L}^{-1} \\ \text{Rate} &= 5 \times 10^{-7} \text{ mol L}^{-1} \text{ s}^{-1} \end{aligned}$$

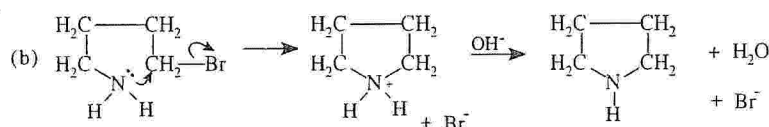
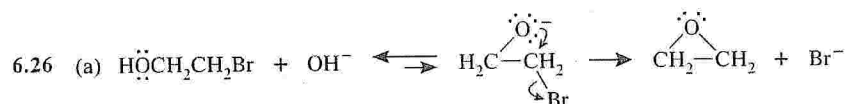
$$\text{(c) } 1 \times 10^{-6} \text{ mol L}^{-1} \text{ s}^{-1}$$

$$\text{(d) } 1 \times 10^{-6} \text{ mol L}^{-1} \text{ s}^{-1}$$

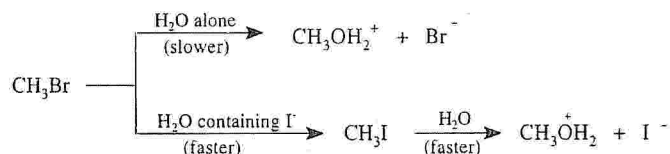
$$\text{(e) } 2 \times 10^{-6} \text{ mol L}^{-1} \text{ s}^{-1}$$



- 6.25 (a)  $\text{CH}_3\text{NH}^-$  because it is the stronger base.  
 (b)  $\text{CH}_3\text{O}^-$  because it is the stronger base.  
 (c)  $\text{CH}_3\text{SH}$  because sulfur atoms are larger and more polarizable than oxygen atoms.  
 (d)  $(\text{C}_6\text{H}_5)_3\text{P}$  because phosphorus atoms are larger and more polarizable than nitrogen atoms.  
 (e)  $\text{H}_2\text{O}$  because it is the stronger base.  
 (f)  $\text{NH}_3$  because it is the stronger base.  
 (g)  $\text{HS}^-$  because it is the stronger base.  
 (h)  $\text{OH}^-$  because it is the stronger base.



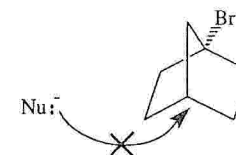
- 6.27 Iodide ion is a good nucleophile and a good leaving group; it can rapidly convert an alkyl chloride or alkyl bromide into an alkyl iodide, and the alkyl iodide can then react rapidly with another nucleophile. With methyl bromide in water, for example, the following reaction can take place:



- 6.28 *tert*-Butyl alcohol and *tert*-butyl methyl ether are formed via an  $\text{S}_{\text{N}}1$  mechanism. The rate of the reaction is independent of the concentration of methoxide ion (from sodium methoxide). This, however, is only one reaction that causes *tert*-butyl bromide to disappear. A competing reaction that also causes *tert*-butyl bromide to disappear is an  $\text{E}2$  reaction in which methoxide ion reacts with *tert*-butyl bromide. This reaction is dependent on the concentration of methoxide ion; therefore, increasing the methoxide ion concentration causes an increase in the rate of disappearance of *tert*-butyl bromide.

- 6.29 (a) You should use a strong-base, such as  $\text{RO}^-$ , at a higher temperature to bring about an  $\text{E}2$  reaction.  
 (b) Here we want an  $\text{S}_{\text{N}}1$  reaction. We use ethanol as the solvent and as the nucleophile, and we carry out the reaction at a low temperature so that elimination will be minimized.

- 6.30 1-Bromobicyclo[2.2.1]heptane is unreactive in an  $\text{S}_{\text{N}}2$  reaction because it is a tertiary halide and its ring structure makes the backside of the carbon bearing the leaving group completely inaccessible to attack by a nucleophile.

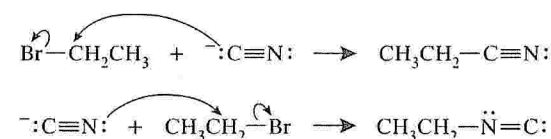


1-Bromobicyclo[2.2.1]heptane is unreactive in an  $\text{S}_{\text{N}}1$  reaction because the ring structure makes it impossible for the carbocation that must be formed to assume the required trigonal planar geometry around the positively charged carbon. Any carbocation formed from 1-bromobicyclo[2.2.1]heptane would have a trigonal pyramidal arrangement of the  $-\text{CH}_2-$  groups attached to the positively charged carbon (make a model). Such a structure does not allow stabilization of the carbocation by overlap of  $sp^2$  orbitals from the alkyl groups (see Fig. 6.9).

- 6.31 The cyanide ion has two nucleophilic atoms; it is what is called an ambident nucleophile.

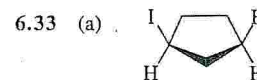
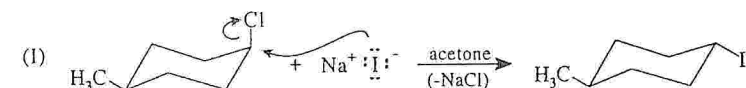
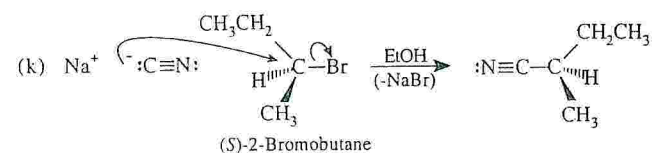
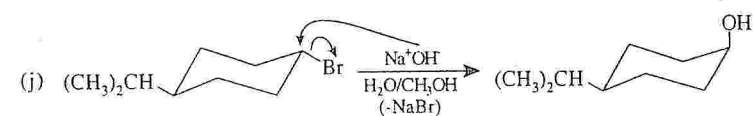
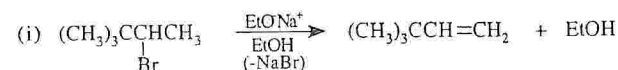
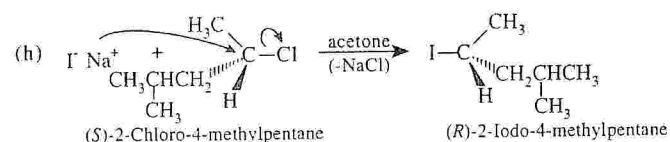
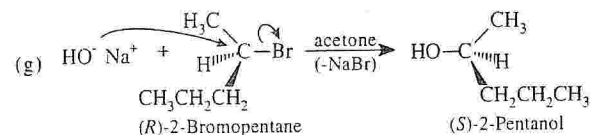
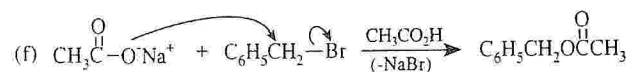
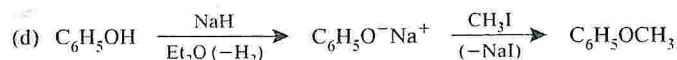
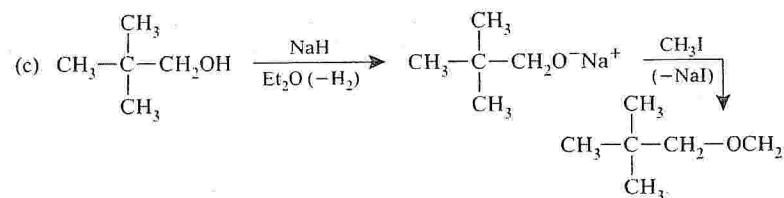


It can react with a substrate using either atom, although the carbon atom is more nucleophilic.

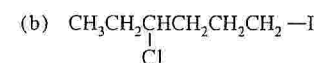


- 6.32 (a)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3 \xrightarrow[\text{Et}_2\text{O}(-\text{H}_2)]{\text{NaH}} \text{CH}_3\text{CH}_2\text{CH}(\text{O}^-\text{Na}^+)\text{CH}_3 \xrightarrow{(-\text{NaBr})} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br} \xrightarrow{(-\text{NaBr})} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{SCH}_3$
- (b)  $(\text{CH}_3)_3\text{CSH} \xrightarrow[\text{Et}_2\text{O}(-\text{H}_2)]{\text{NaH}} (\text{CH}_3)_3\text{CS}^-\text{Na}^+ \xrightarrow[\text{CH}_3\text{CH}_2\text{Br}]{(-\text{NaBr})} (\text{CH}_3)_3\text{C}-\text{S}-\text{CH}_2\text{CH}_3$

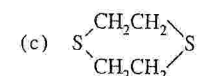




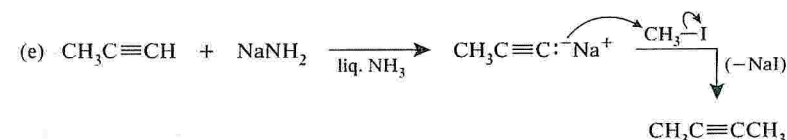
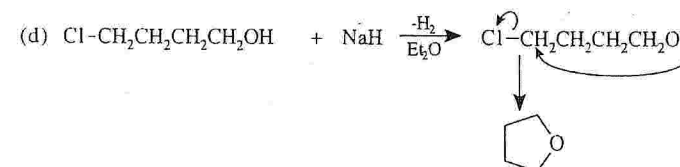
(Formation of this product depends on the fact that bromide ion is a much better leaving group than fluoride ion.)



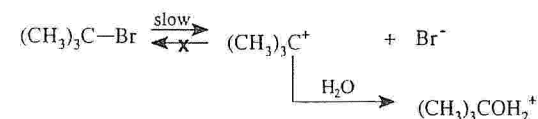
(Formation of this product depends on the greater reactivity of 1° substrates in  $\text{S}_{\text{N}}2$  reactions.)



(Here two  $\text{S}_{\text{N}}2$  reactions produce a cyclic molecule.)

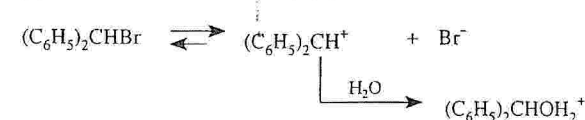


6.34 The rate-determining step in the  $\text{S}_{\text{N}}1$  reaction of *tert*-butyl bromide is the following:



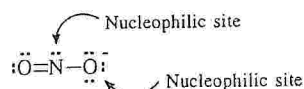
$(\text{CH}_3)_3\text{C}^+$  is so unstable that it reacts almost immediately with one of the surrounding water molecules, and, for all practical purposes, no reverse reaction with  $\text{Br}^-$  takes place. Adding a common ion ( $\text{Br}^-$  from  $\text{NaBr}$ ), therefore, has no effect on the rate.

Because the  $(\text{C}_6\text{H}_5)_2\text{CH}^+$  cation is more stable, a reversible first step occurs and adding a common ion ( $\text{Br}^-$ ) slows the overall reaction by increasing the rate at which  $(\text{C}_6\text{H}_5)_2\text{CH}^+$  is converted back to  $(\text{C}_6\text{H}_5)_2\text{CHBr}$ .

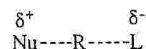


6.35 Two different mechanisms are involved.  $(\text{CH}_3)_3\text{CBr}$  reacts by an  $\text{S}_{\text{N}}1$  mechanism, and apparently this reaction takes place faster. The other three alkyl halides react by an  $\text{S}_{\text{N}}2$  mechanism, and their reactions are slower because the nucleophile ( $\text{H}_2\text{O}$ ) is weak. The reaction rates of  $\text{CH}_3\text{Br}$ ,  $\text{CH}_3\text{CH}_2\text{Br}$ , and  $(\text{CH}_3)_2\text{CHBr}$  are affected by the steric hindrance, and thus their order of reactivity is  $\text{CH}_3\text{Br} > \text{CH}_3\text{CH}_2\text{Br} > (\text{CH}_3)_2\text{CHBr}$ .

- 6.36 The nitrite ion is an *ambident nucleophile*; that is, it is an ion with two nucleophilic sites. The equivalent oxygen atoms and the nitrogen atom are nucleophilic.



- 6.37 (a) The transition state has the form:

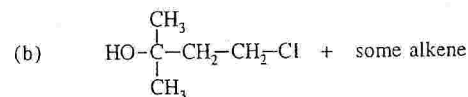
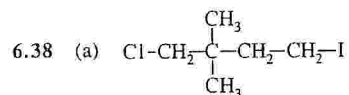


in which charges are developing. The more polar the solvent, the better it can solvate the transition state, thus lowering the free energy of activation and increasing the reaction rate.

- (b) The transition state has the form:



in which the charge is becoming dispersed. A polar solvent is less able to solvate this transition state than it is to solvate the reactant. The free energy of activation, therefore, will become somewhat larger as the solvent polarity increases, and the rate will be slower.



- 6.39 (a) In an  $\text{S}_{\text{N}}1$  reaction the carbocation intermediate reacts rapidly with any nucleophile it encounters in a Lewis acid-Lewis base reaction. In the case of the  $\text{S}_{\text{N}}2$  reaction, the leaving group departs only when "pushed out" by the attacking nucleophile, and some nucleophiles are better than others.

(b)  $\text{CN}^-$  is a much better nucleophile than ethanol and hence the nitrile is formed in the  $\text{S}_{\text{N}}2$  reaction of  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$ . In the case of  $(\text{CH}_3)_3\text{CCl}$  the *tert*-butyl cation reacts chiefly with the nucleophile present in higher concentration, here the ethanol solvent.

\*6.40

|                                                                                                     | $\Delta H^\circ, \text{kJ mol}^{-1}$ |                                      |
|-----------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------------------|
| $(\text{CH}_3)_3\text{C}-\text{Cl} \longrightarrow (\text{CH}_3)_3\text{C}^\cdot + \text{Cl}^\cdot$ | +328                                 | Homolytic bond dissociation energy   |
| $(\text{CH}_3)_3\text{C}^\cdot \longrightarrow (\text{CH}_3)_3\text{C}^+ + \text{e}^-$              | +715                                 | Ionization potential                 |
| $\text{Cl}^\cdot + \text{e}^- \longrightarrow \text{Cl}^-$                                          | -330                                 | Electron affinity                    |
| $(\text{CH}_3)_3\text{C}-\text{Cl} \longrightarrow (\text{CH}_3)_3\text{C}^+ + \text{Cl}^-$         | +713                                 | Heterolytic bond dissociation energy |

- \*6.41 (a) The entropy term is slightly favorable. (The enthalpy term is highly unfavorable.)

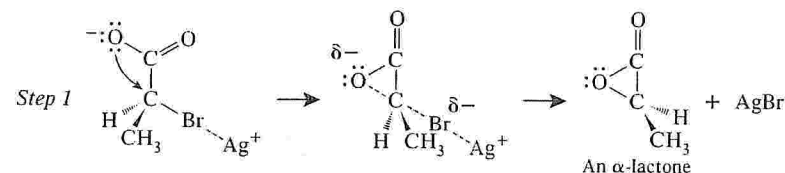
$$\begin{aligned} (b) \quad \Delta G^\circ &= \Delta H^\circ - T\Delta S^\circ \\ &= 26.6 \text{ kJ mol}^{-1} - (298)(0.00481 \text{ kJ mol}^{-1}) \\ &= 25.2 \text{ kJ mol}^{-1} \end{aligned}$$

$$\begin{aligned} (c) \quad \log K_{\text{eq}} &= \frac{-\Delta G^\circ}{2.303RT} \\ &= \frac{-25.2 \text{ kJ mol}^{-1}}{(2.303)(0.008314 \text{ kJ mol}^{-1} \text{ K}^{-1})(298 \text{ K})} \\ &= -4.4165 \end{aligned}$$

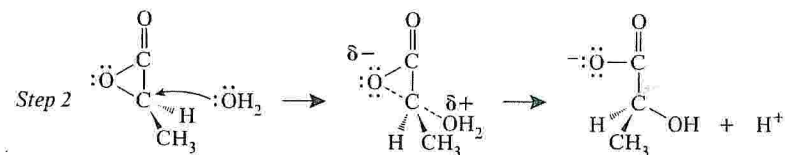
$$K_{\text{eq}} = 10^{-4.4165} = 3.85 \times 10^{-5}$$

- (d) The equilibrium is very much more favorable in aqueous solution because solvation of the products (ethanol, hydronium ions, and chloride ions) takes place and thereby stabilizes them.

- \*6.42 The mechanism for the reaction involves the participation of the carboxylate group. In step 1 (see following reaction) an oxygen of the carboxylate group attacks the stereocenter from the backside and displaces bromide ion. (Silver ion aids in this process in much the same way that protonation assists the ionization of an alcohol.) The configuration of the stereocenter inverts in step 1, and a cyclic ester called an  $\alpha$ -lactone forms.

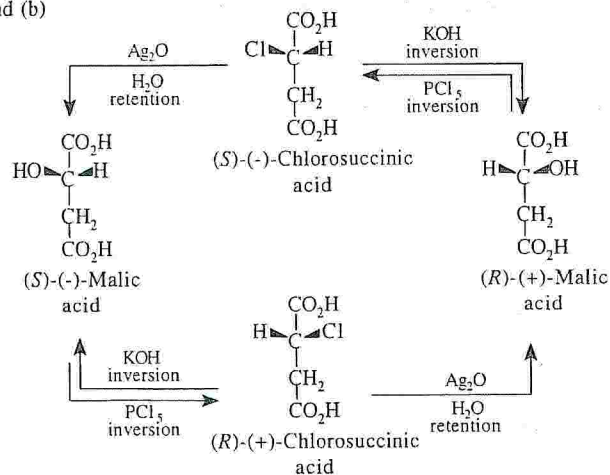


The highly strained three-membered ring of the  $\alpha$ -lactone opens when it is attacked by a water molecule in step 2. *This step also takes place with an inversion of configuration.*



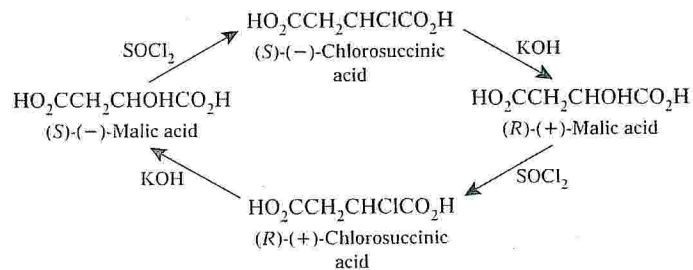
The net result of two inversions (in steps 1 and 2) is an overall *retention of configuration*.

\*6.43 (a) and (b)

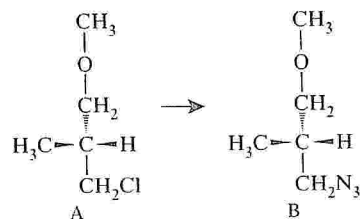


(c) The reaction takes place with retention of configuration.

(d)



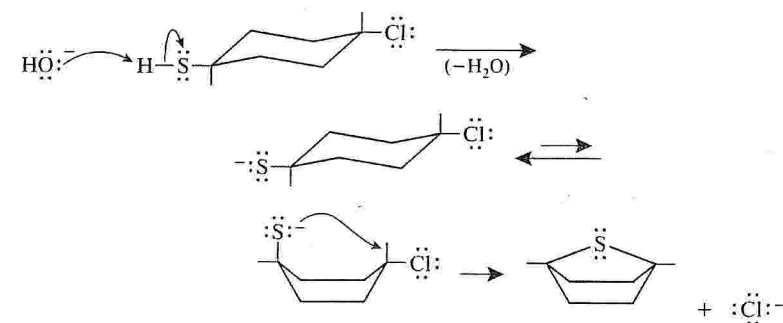
\*6.44



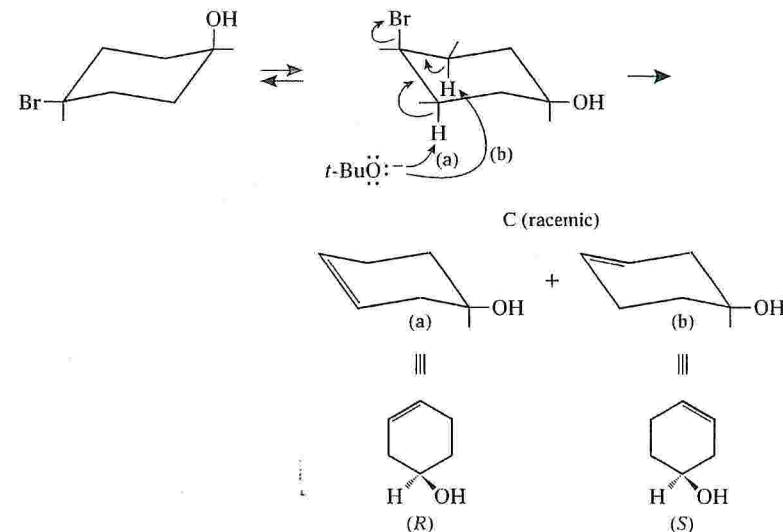
No change of configuration occurs, just a change in the relative priority of a group at the stereocenter.

\*6.45 Comparison of the molecular formulas of starting material and product indicates a loss of HCl. The absence of IR bands in the  $1620\text{--}1680\text{ cm}^{-1}$  region rules out the presence of the alkene function.

A nucleophilic substitution agrees with the evidence:



\*6.46 The IR evidence indicates that C possesses both an alkene function and a hydroxyl group. An E2 reaction on this substrate produces enantiomeric unsaturated alcohols.



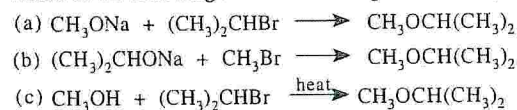
## QUIZ

- 6.1 Which set of conditions would you use to obtain the best yield in the reaction shown?



- (a)  $\text{H}_2\text{O}$ , heat      (b)  $\text{CH}_3\text{CH}_2\text{ONa}/\text{CH}_3\text{CH}_2\text{OH}$ , heat      (c) Heat alone  
(d)  $\text{H}_2\text{SO}_4$       (e) None of the above

- 6.2 Which of the following reactions would give the best yield?



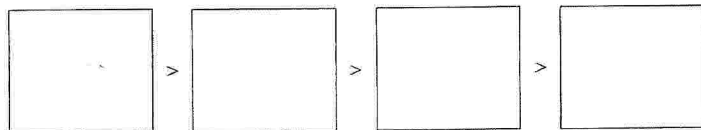
- 6.3 A kinetic study yielded the following reaction rate data:

| Experiment Number | Initial Concentrations |                 | Initial Rate of Disappearance of R—Br and Formation of R—OH |
|-------------------|------------------------|-----------------|-------------------------------------------------------------|
|                   | $[\text{OH}^-]$        | $[\text{R—Br}]$ |                                                             |
| 1                 | 0.50                   | 0.50            | 1.00                                                        |
| 2                 | 0.50                   | 0.25            | 0.50                                                        |
| 3                 | 0.25                   | 0.25            | 0.25                                                        |

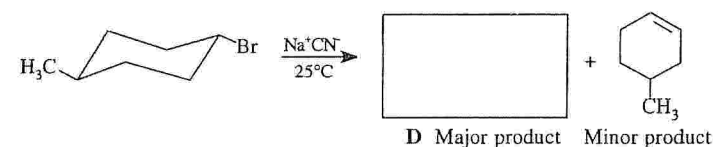
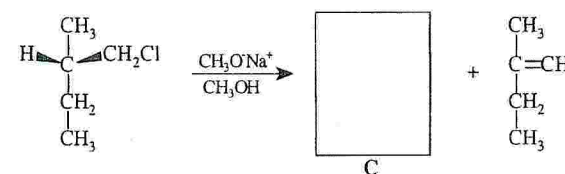
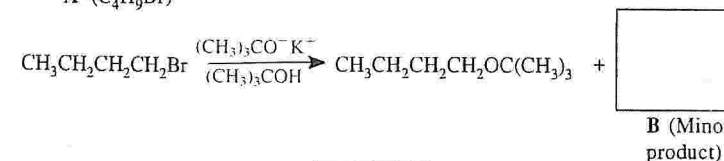
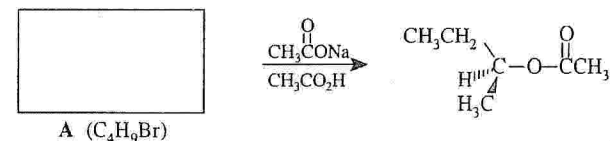
Which of the following statements best describe this reaction?

- (a) The reaction is second order.      (b) The reaction is first order.  
 (c) The reaction is  $\text{S}_{\text{N}}1$ .      (d) Increasing the concentration of  $\text{OH}^-$  has no effect on the rate.  
 (e) More than one of the above.

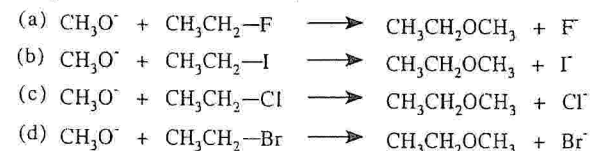
- 6.4 There are four compounds with the formula  $\text{C}_4\text{H}_9\text{Br}$ . List them in order of decreasing reactivity in an  $\text{S}_{\text{N}}2$  reaction.



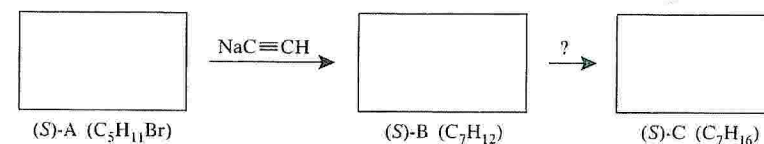
- 6.5 Supply the missing reactants, reagents, intermediates, or products.



- 6.6 Which  $\text{S}_{\text{N}}2$  reaction will occur most rapidly. (Assume the concentrations and temperatures are all the same.)



- 6.7 Provide three-dimensional structures for the missing boxed structures and formulas for missing reagents.





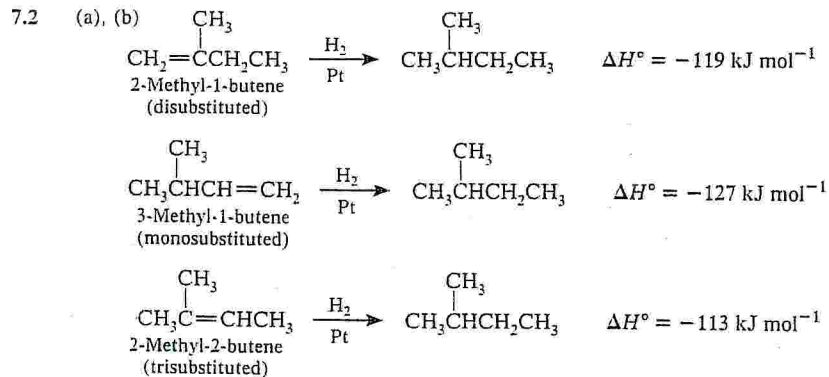


## 7

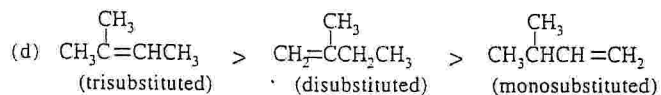
ALKENES AND ALKYNES I:  
PROPERTIES AND SYNTHESIS

## SOLUTIONS TO PROBLEMS

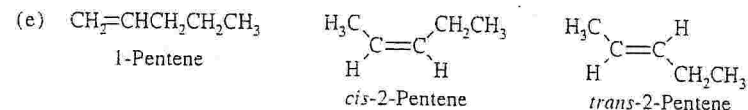
- 7.1 (a) (*E*)-1-Bromo-1-chloro-1-pentene  
 (b) (*E*)-2-Bromo-1-chloro-1-iodo-1-butene  
 (c) (*Z*)-3,5-Dimethyl-2-hexene  
 (d) (*Z*)-1-Chloro-1-iodo-2-methyl-1-butene  
 (e) (*Z*,4*S*)-3,4-Dimethyl-2-hexene  
 (f) (*Z*,3*S*)-1-Bromo-2-chloro-3-methyl-1-hexene



- (c) Yes, because hydrogenation converts each alkene into the same product.



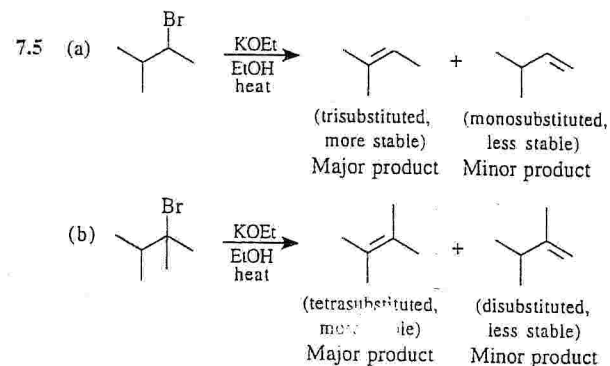
Notice that this predicted order of stability is confirmed by the heats of hydrogenation. 2-Methyl-2-butene evolves the least heat; therefore, it is the most stable. 3-Methyl-1-butene evolves the most heat; therefore, it is the least stable.



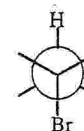
- (f) Heats of combustion, because complete combustion would convert all of the alkenes to the same products. (All of the alkenes have the formula  $\text{C}_5\text{H}_{10}$ .)  
 $\text{C}_5\text{H}_{10} + 7\frac{1}{2} \text{O}_2 \longrightarrow 5 \text{CO}_2 + 5 \text{H}_2\text{O}$

- 7.3 (a) 2,3-Dimethyl-2-butene would be the more stable because the double bond is tetrasubstituted. 2-Methyl-2-pentene has a trisubstituted double bond.  
 (b) *trans*-3-Hexene would be the more stable because alkenes with *trans* double bonds are more stable than those with *cis* double bonds.  
 (c) *cis*-3-Hexene would be more stable because its double bond is disubstituted. The double bond of 1-hexene is monosubstituted.  
 (d) 2-Methyl-2-pentene would be the more stable because its double bond is trisubstituted. The double bond of *trans*-2-hexene is disubstituted.

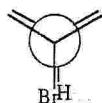
- 7.4 The relative stabilities of the pairs of alkenes in parts (b) and (c) in Problem 7.3 could be determined by measuring heats of hydrogenation, because in each instance the two alkenes would yield the same product. Heats of combustion could be used to determine the relative stabilities of the alkene pairs in parts (a) and (d) [and also those in parts (b) and (c)] because on complete combustion the alkenes produce the same number of molar equivalents of  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .



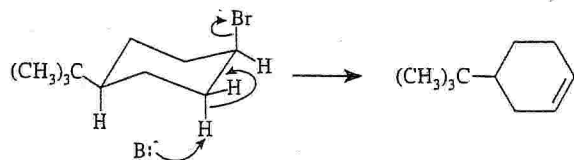
- 7.6 An anti periplanar transition state allows the molecule to assume the more stable staggered conformation.



whereas a syn periplanar transition state requires the molecule to assume the less stable eclipsed conformation:

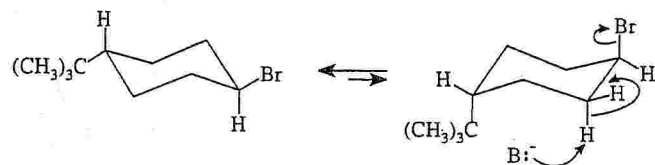


- 7.7 *cis*-1-Bromo-4-*tert*-butylcyclohexane can assume an anti periplanar transition state in which the bulky *tert*-butyl group is equatorial:



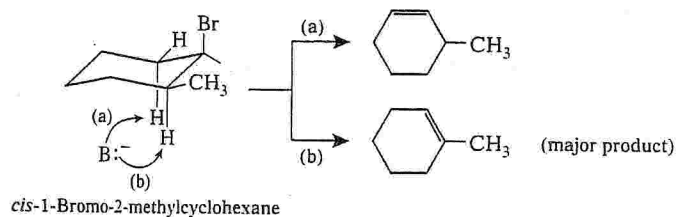
The conformation (above), because it is relatively stable, is assumed by most of the molecules present, and, therefore, the reaction is rapid.

On the other hand, for *trans*-1-bromo-4-*tert*-butylcyclohexane to assume an anti periplanar transition state, the molecule must assume a conformation in which the large *tert*-butyl group is axial:

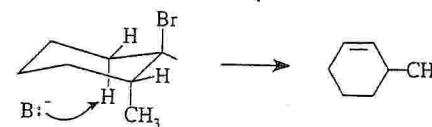


Such a conformation is of high energy; therefore, very few molecules assume this conformation. The reaction, consequently, is very slow.

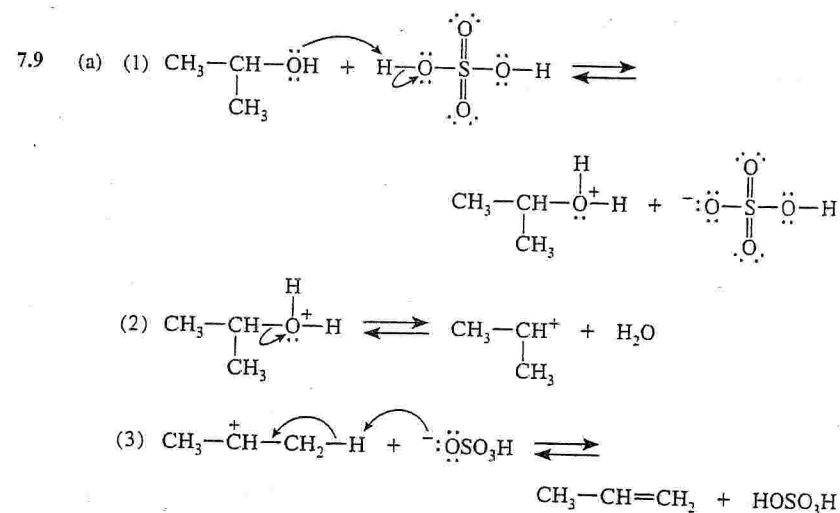
- 7.8 (a) Anti periplanar elimination can occur in two ways with the *cis* isomer.



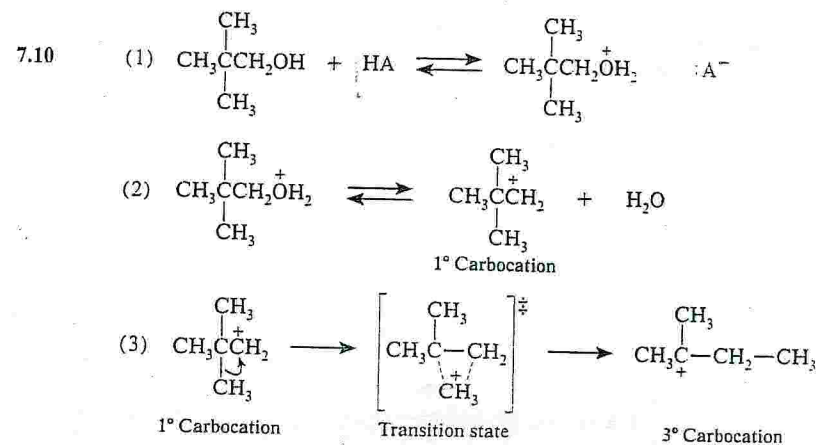
- (b) Anti periplanar elimination can occur in only one way with the *trans* isomer.

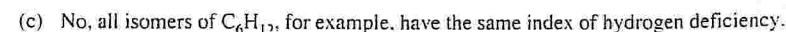
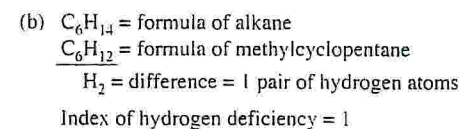
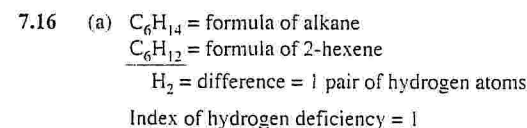
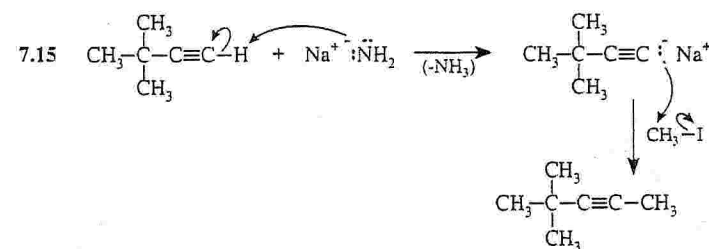
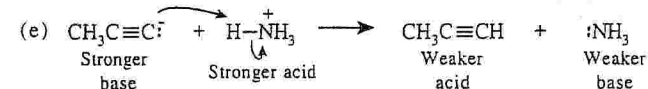
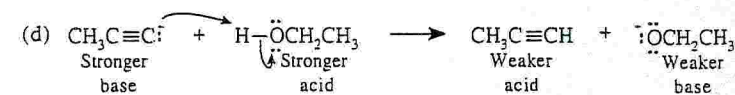
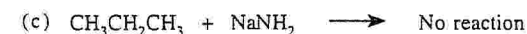
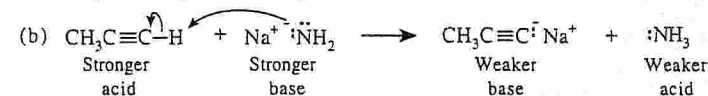
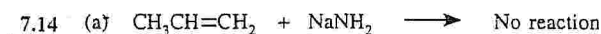
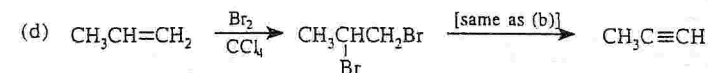
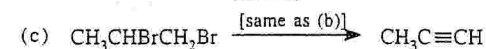
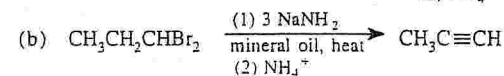
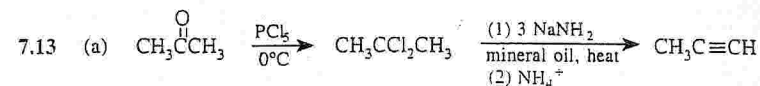
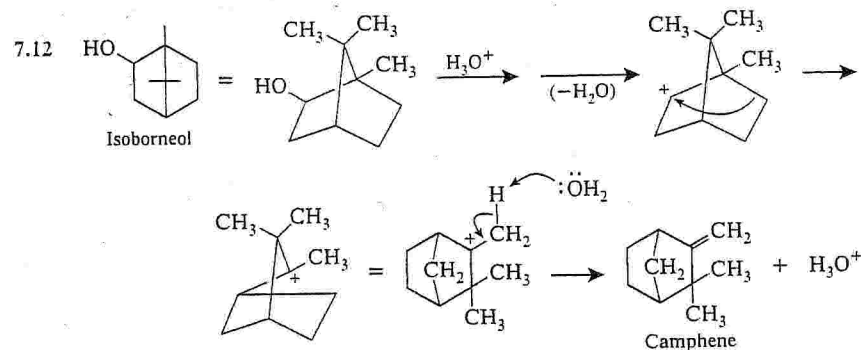
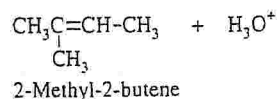
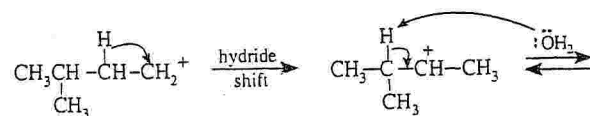
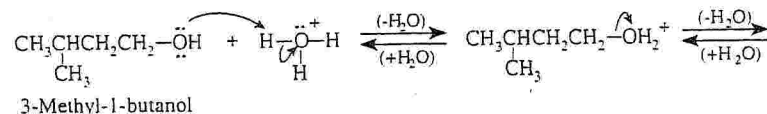
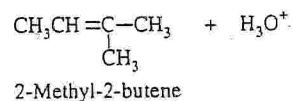
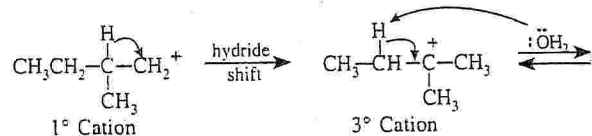
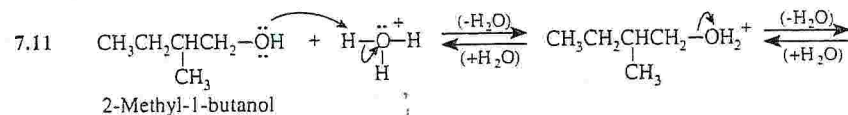
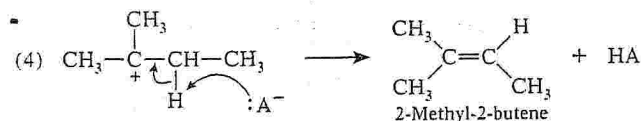


*trans*-1-Bromo-2-methylcyclohexane



- (b) By donating a proton to the  $-\text{OH}$  group of the alcohol in step (1), the acid allows the loss of a relatively stable, weakly basic, leaving group ( $\text{H}_2\text{O}$ ) in step (2). In the absence of an acid, the leaving group would have to be the strongly basic  $\text{OH}^-$  ion, and such steps almost never occur.







(d) No

(e)  $C_6H_{14}$  = formula of alkane $C_6H_{10}$  = formula of 2-hexyne $H_4$  = difference = 2 pairs of hydrogen atoms

Index of hydrogen deficiency = 2

(f)  $C_{10}H_{22}$  (alkane) $C_{10}H_{16}$  (compound) $H_6$  = difference = 3 pairs of hydrogen atoms

Index of hydrogen deficiency = 3

The structural possibilities are thus

3 double bonds

1 double bond and one triple bond

2 double bonds and 1 ring

1 double bond and 2 rings

3 rings

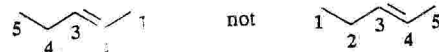
1 triple bond and one ring

7.17 (a)  $C_{15}H_{32}$  = formula of alkane $C_{15}H_{24}$  = formula of zingiberene $H_8$  = difference = 4 pairs of hydrogen atoms

Index of hydrogen deficiency = 4

(b) Since 1 mol of zingiberene absorbs 3 mol of hydrogen, one molecule of zingiberene must contain three double bonds. (We are told that molecules of zingiberene do not contain any triple bonds.)

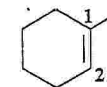
(c) If a molecule of zingiberene has three double bonds and an index of hydrogen deficiency equal to 4, it must have one ring. (The structural formula for zingiberene can be found in Problem 23.2.)

7.18 (a) We designate the position of the double bond by using the *lower* number of the two numbers of the doubly bonded carbon atoms, and the chain is numbered from the end nearer the double bond. The correct name is *trans*-2-pentene

(b) We must choose the longest chain for the base name. The correct name is 2-methylpropene.



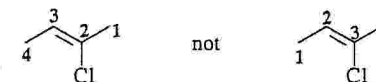
(c) We use the lower number of the two doubly bonded carbon atoms to designate the position of the double bond. The correct name is 1-methylcyclohexene.



(d) We must number the ring starting with the double bond in the direction that gives the substituent the lower number. The correct name is 3-methylcyclobutene.



(e) We number in the way that gives the double bond and the substituent the lower number. The correct name is (Z)-2-chloro-2-butene.



(f) We number the ring starting with the double bond so as to give the substituents the lower numbers. The correct name is 3,4-dichlorocyclohexene.



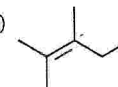
7.19 (a)



(b)



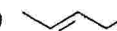
(c)



(d)



(e)



(f)



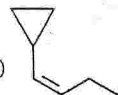
(g)



(h)



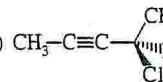
(i)



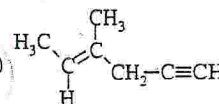
(j)

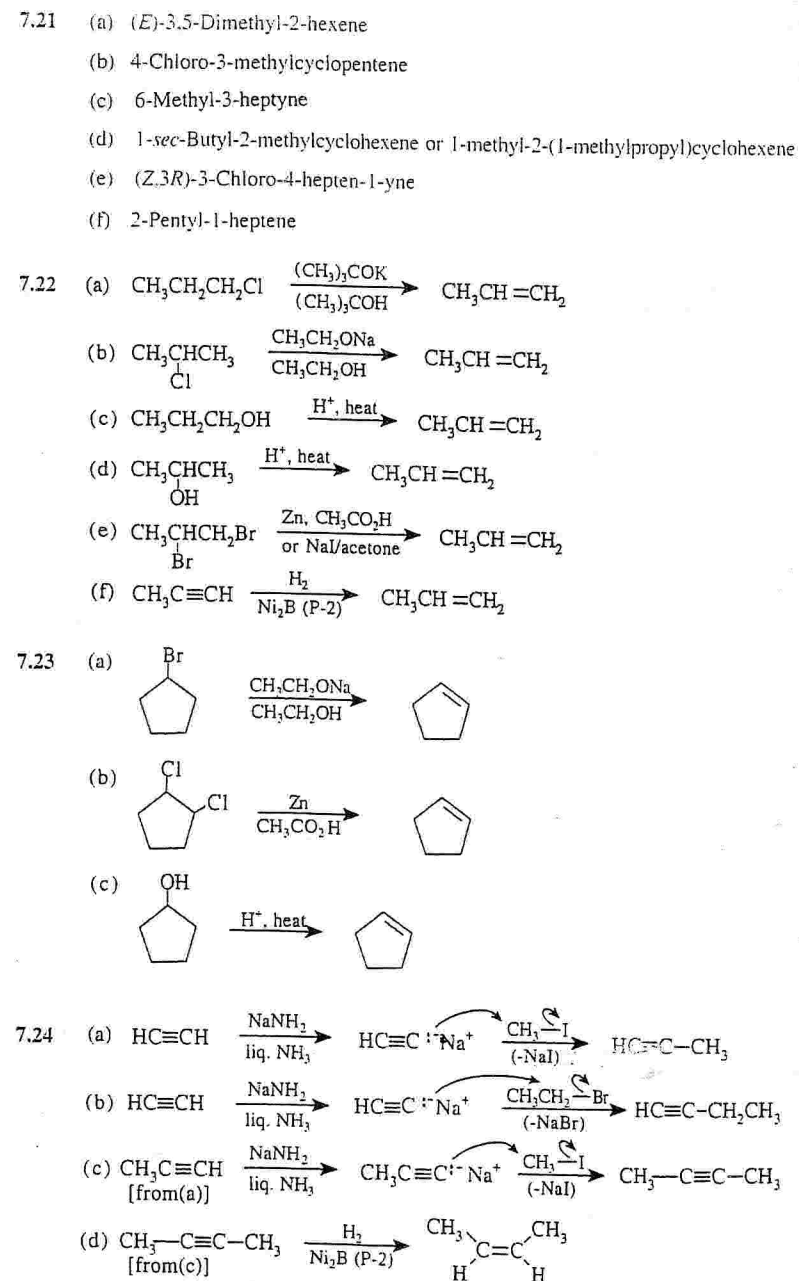
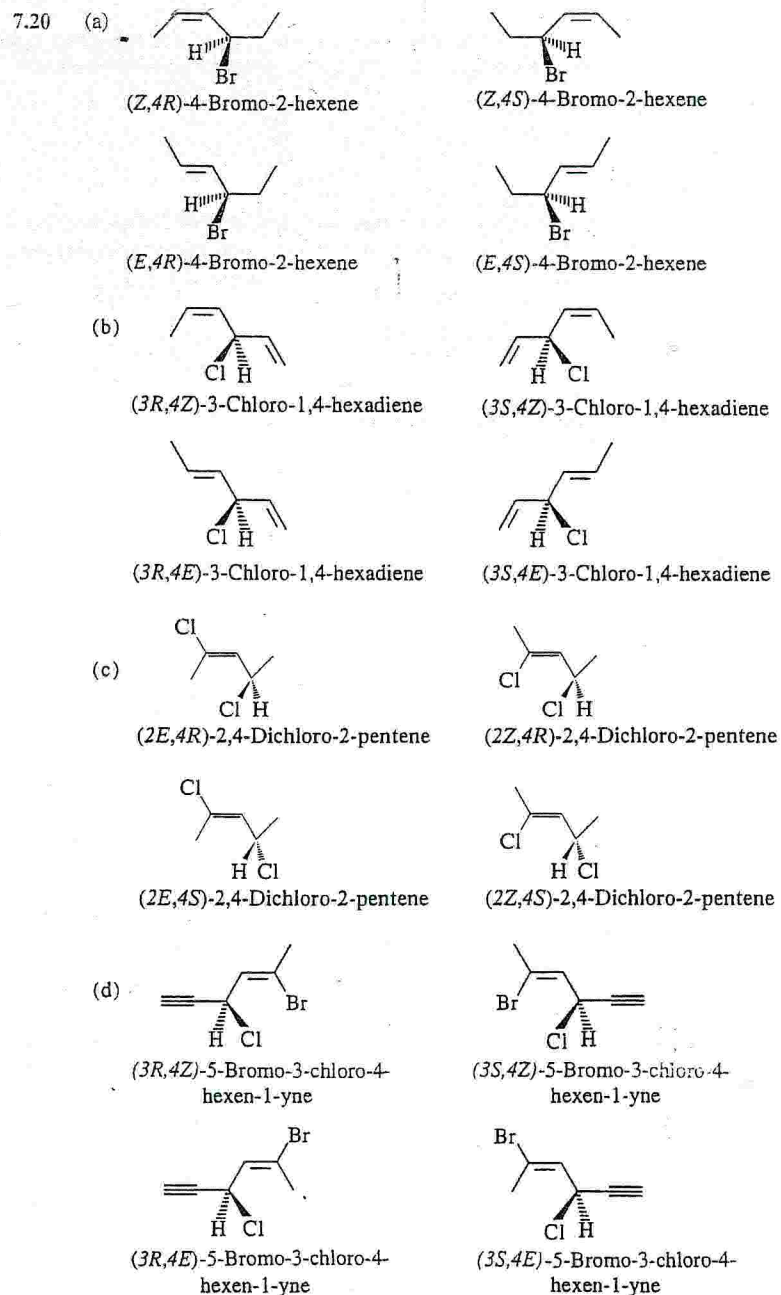


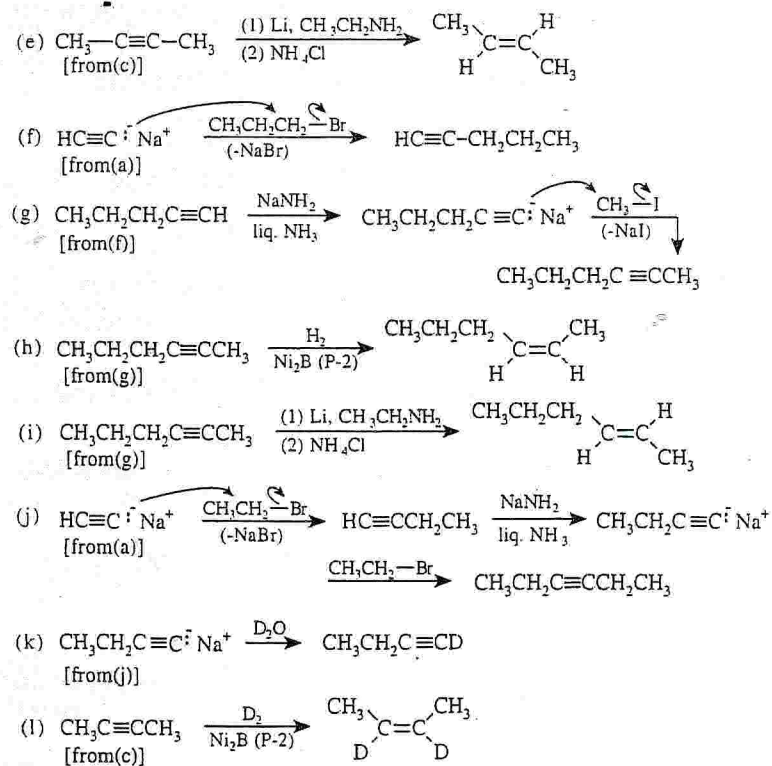
(k)



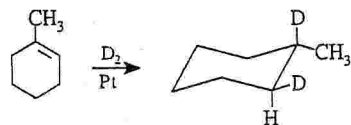
(l)



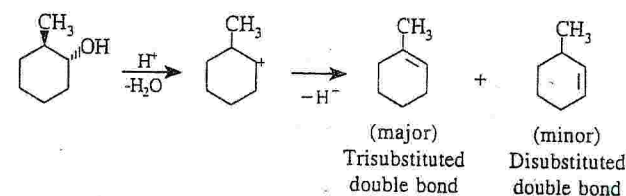




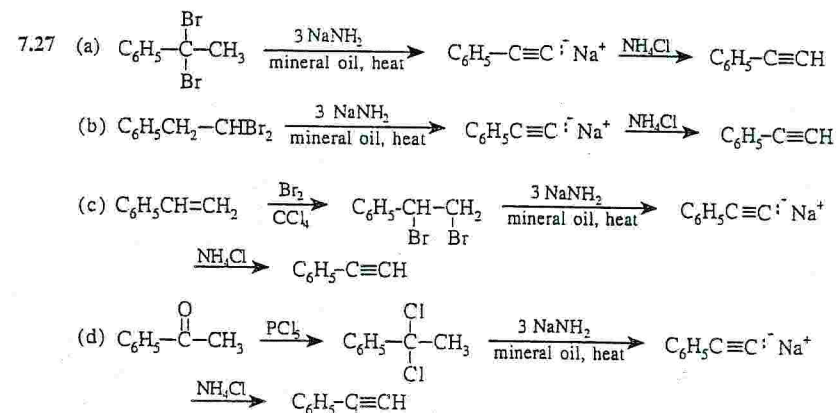
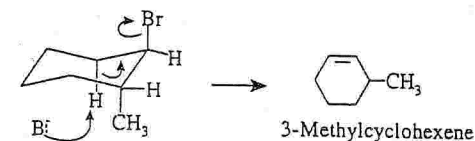
7.25 We notice that the deuterium atoms are *cis* to each other, and we conclude, therefore, that we need to choose a method that will cause a *syn* addition of deuterium. One way would be to use  $\text{D}_2$  and a metal catalyst (Section 7.13)



7.26 Dehydration of *trans*-2-methylcyclohexanol proceeds through the formation of a carbocation (through an E1 reaction of the protonated alcohol) and leads preferentially to the more stable alkene. 1-Methylcyclohexene (below) is more stable than 3-methylcyclohexene (the minor product of the dehydration) because its double bond is more highly substituted.



Dehydrohalogenation of *trans*-1-bromo-2-methylcyclohexane is an E2 reaction and must proceed through an anti periplanar transition state. Such a transition state is possible only for the elimination leading to 3-methylcyclohexene (cf. Problem 7.8).

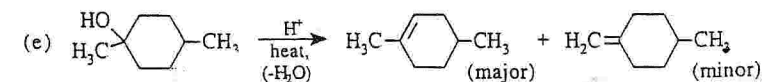
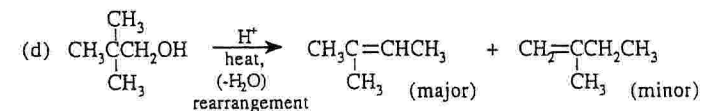
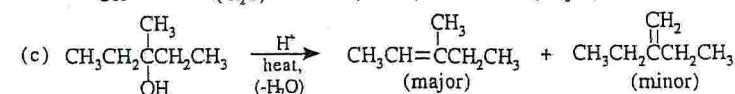
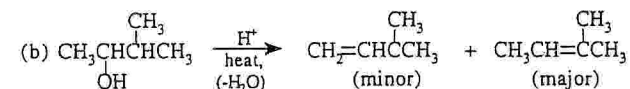
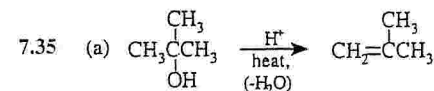
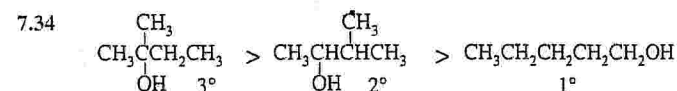
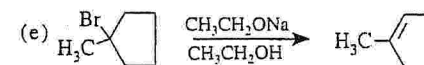
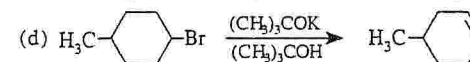
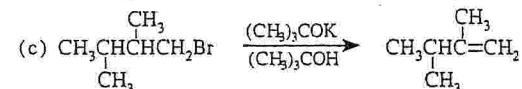
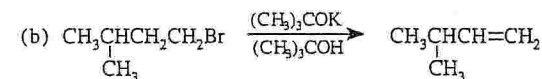
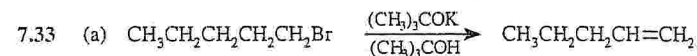
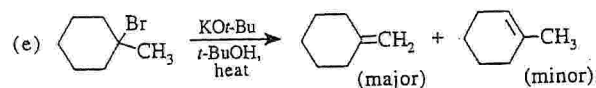
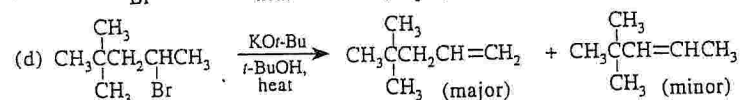
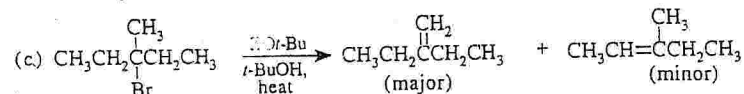
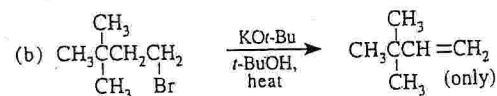
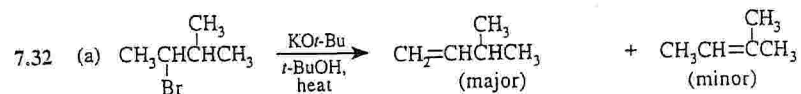
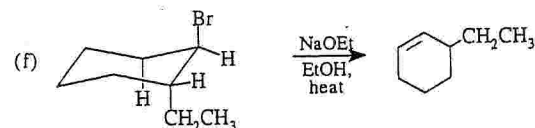
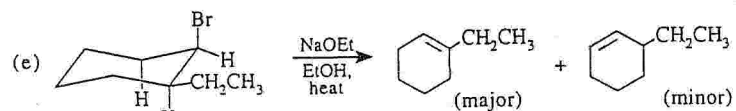
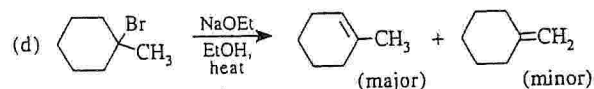
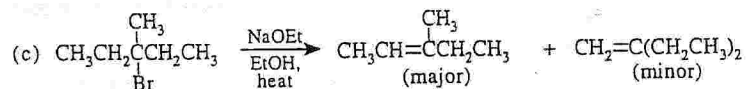
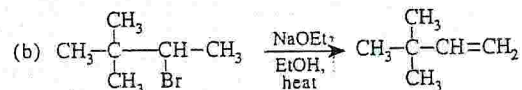
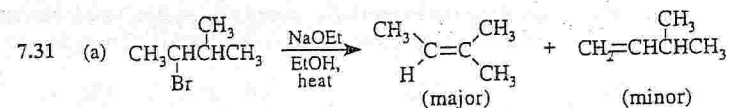


7.28 Cyclobutane is less stable than any of the butene isomers.

7.29 1-Pentene, 3375 kJ mol<sup>-1</sup>  
*cis*-2-Pentene, 3369 kJ mol<sup>-1</sup>  
*trans*-2-Pentene, 3365 kJ mol<sup>-1</sup>  
 2-Methyl-1-butene, 3361 kJ mol<sup>-1</sup>  
 2-Methyl-2-butene, 3355 kJ mol<sup>-1</sup>



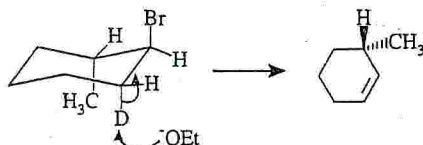
7.30 1-Pentanol > 1-pentyne > 1-pentene > pentane  
(See Section 3.7 for the explanation.)



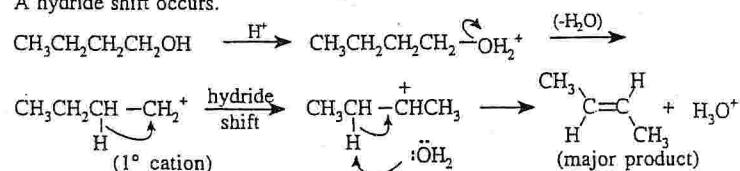
7.36 The alkene cannot be formed because the double bond in the product is too highly strained. Recall that the atoms at each carbon of a double bond prefer to be in the same plane.



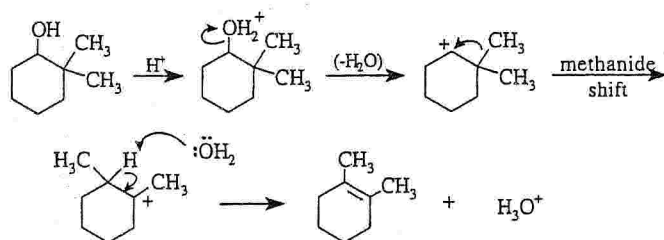
- 7.37 Only the deuterium atom can assume the anti periplanar orientation necessary for an E2 reaction to occur.



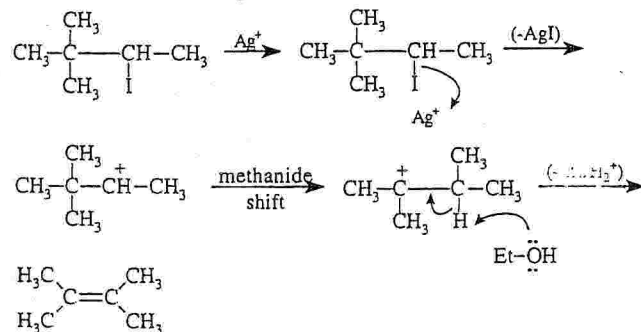
- 7.38 (a) A hydride shift occurs.



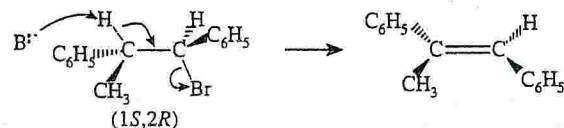
- (b) A methanide shift occurs.



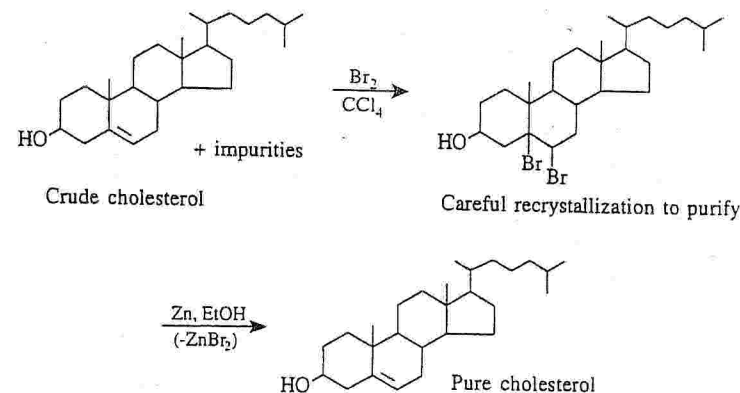
- (c) A methanide shift occurs.



- (d) The required anti periplanar transition state leads only to (E) alkene:



- 7.39 In the first step, cholesterol reacts with bromine to form the *vic*-dibromide. This product is then purified by crystallization, and then treatment with zinc in ethanol converts the pure *vic*-dibromide back to cholesterol. (Recrystallization of the *vic*-dibromide is especially easy because it has a higher melting point than cholesterol.)



- 7.40 (a) Caryophyllene has the same molecular formula as zingiberene (Problem 7.17); thus, it, too, has an index of hydrogen deficiency equal to 4. That 1 mol of caryophyllene absorbs 2 mol of hydrogen on catalytic hydrogenation indicates the presence of two double bonds per molecule.

(b) Caryophyllene molecules must also have two rings. (See Problem 23.2 for the structure of caryophyllene.)

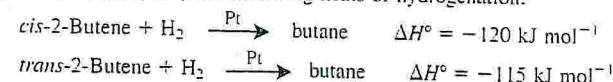
- 7.41 (a)  $\text{C}_{30}\text{H}_{62}$  = formula of alkane  
 $\text{C}_{30}\text{H}_{50}$  = formula of squalene  
 $\text{H}_{12}$  = difference = 6 pairs of hydrogen atoms

Index of hydrogen deficiency = 6

(b) Molecules of squalene contain six double bonds.

(c) Squalene molecules contain no rings. (See Problem 23.2 for the structural formula of squalene.)

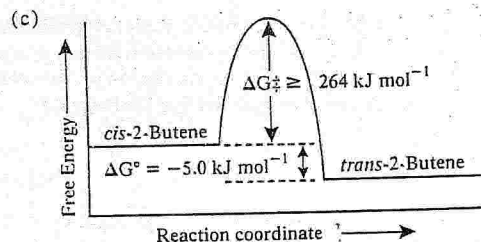
- 7.42 (a) We are given (Section 7.3A) the following heats of hydrogenation:



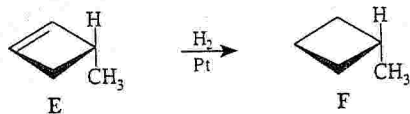
Thus, for



(b) Converting *cis*-2-butene into *trans*-2-butene involves breaking the  $\pi$  bond. Therefore, we would expect the energy of activation to be at least as large as the  $\pi$ -bond strength, that is, at least 264 kJ mol<sup>-1</sup>.



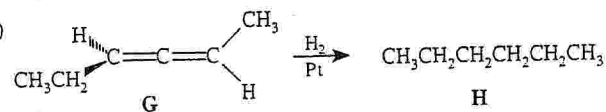
7.43 (a)



Optically active (the enantiomeric form is an equally valid answer)

Optically inactive and nonresolvable

(b)

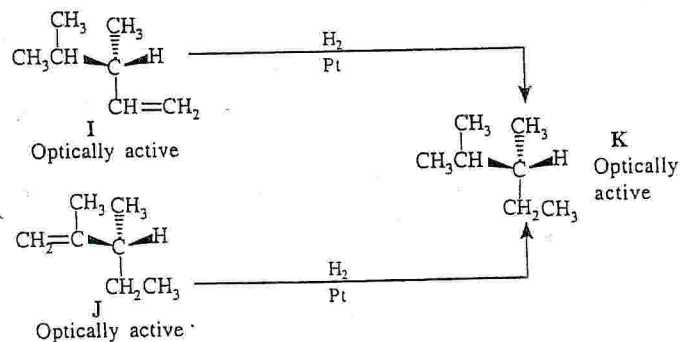


Optically active (the enantiomeric form is an equally valid answer)

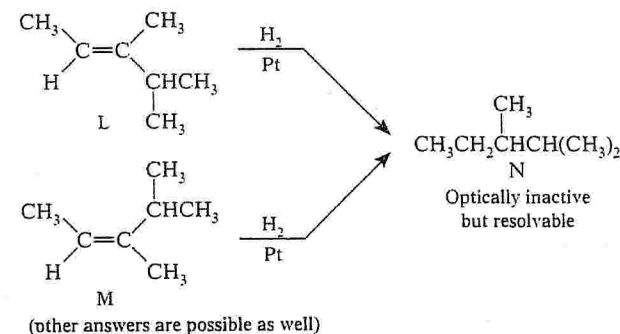
Optically inactive and nonresolvable

7.44

That I and J rotate plane-polarized light in the same direction tells us that I and J are not enantiomers of each other. Thus, the following are possible structures for I, J, and K. (The enantiomers of I, J, and K would form another set of structures, and other answers are possible as well.)

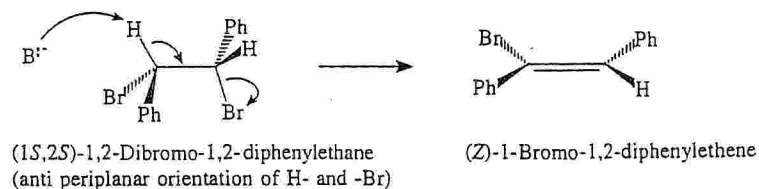
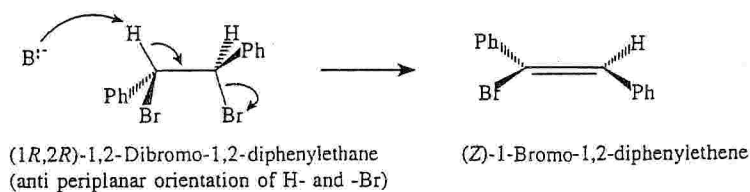


7.45 The following are possible structures:

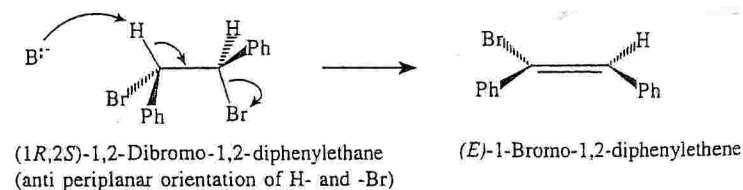


7.46

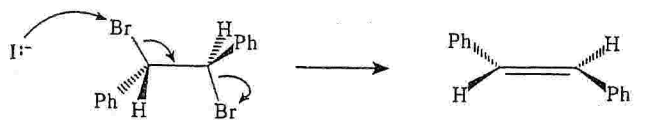
(a) With either the (1*R*,2*R*)- or the (1*S*,2*S*)-1,2-dibromo-1,2-diphenylethane, only one conformation will allow an anti periplanar arrangement of the H- and Br-. In either case, the elimination leads only to (Z)-1-bromo-1,2-diphenylethene:



(b) With (1*R*,2*S*)-1,2-dibromo-1,2-diphenylethane, only one conformation will allow an anti periplanar arrangement of the H- and Br-. In this case, the elimination leads only to (*E*)-1-bromo-1,2-diphenylethene:

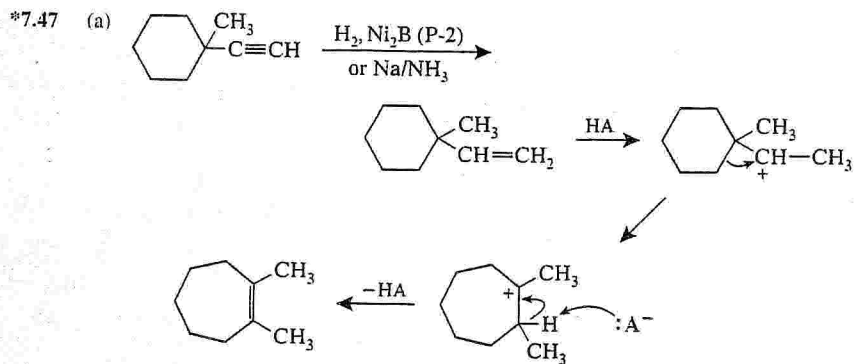


(c) With (1*R*,2*S*)-1,2-dibromo-1,2-diphenylethane, only one conformation will allow an anti periplanar arrangement of both bromine atoms. In this case, the elimination leads only to (*E*)-1,2-diphenylethene:

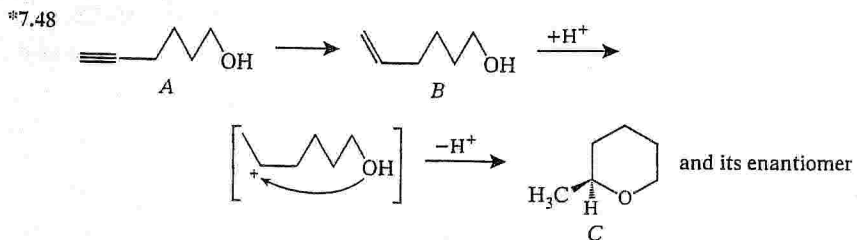


(1*R*,2*S*)-1,2-Dibromo-1,2-diphenylethane  
(anti periplanar orientation of both -Br atoms)

(*E*)-1,2-Diphenylethene



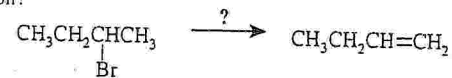
(b) No, tetrasubstituted double bonds usually show no  $C=C$  stretching absorption in their infrared spectra.



- \*7.49 (a) Three  
(b) Six

## QUIZ

- 7.1 Which conditions/reagents would you employ to obtain the best yields in the following reaction?

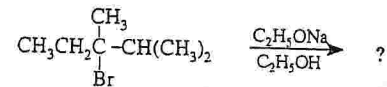


- (a)  $\text{H}_2\text{O}/\text{heat}$  (c)  $(\text{CH}_3)_3\text{COK}/(\text{CH}_3)_3\text{COH}, \text{heat}$   
(b)  $\text{CH}_3\text{CH}_2\text{ONa}/\text{CH}_3\text{CH}_2\text{OH}, \text{heat}$  (d) Reaction cannot occur as shown

- 7.2 Which of the following names is incorrect?

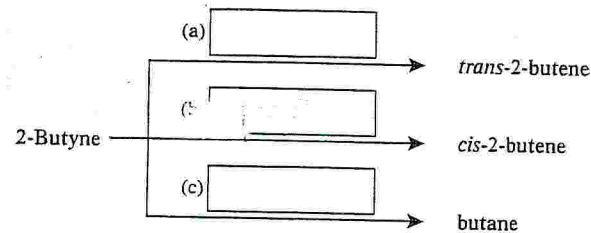
- (a) 1-Butene      (b) *trans*-2-Butene      (c) (Z)-2-Chloro-2-pentene  
(d) 1,1-Dimethylcyclopentene      (e) Cyclohexene

- 7.3 Select the major product of the reaction

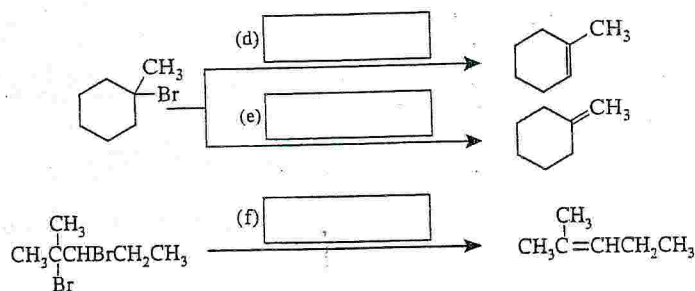


- (a)  $\text{CH}_3\text{CH}_2\overset{\text{CH}_3}{\underset{|}{\text{C}}}=\text{C}(\text{CH}_3)_2$
- (b)  $\text{CH}_3\text{CH}_2\overset{\text{CH}_2}{\underset{|}{\text{C}}}-\text{CH}(\text{CH}_3)_2$
- (c)  $\text{CH}_3\text{CH}=\overset{\text{CH}_3}{\underset{|}{\text{C}}}-\text{CH}(\text{CH}_3)_2$
- (d)  $\text{CH}_2=\text{CH}-\overset{\text{CH}_3}{\underset{|}{\text{CH}}}-\text{CH}(\text{CH}_3)_2$
- (e)  $\text{CH}_3\text{CH}_2\overset{\text{CH}_3}{\underset{\text{OC}_2\text{H}_5}{|}{\text{C}}}-\text{CH}(\text{CH}_3)_2$

- 7.4 Supply the missing reagents.

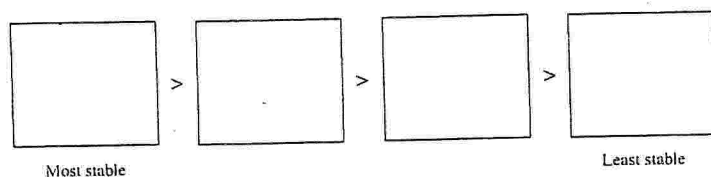




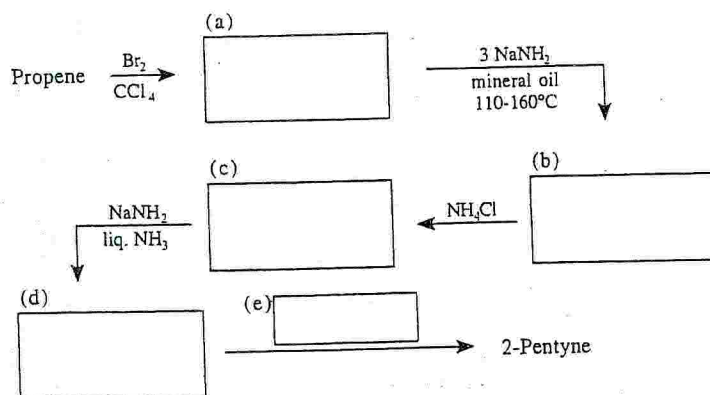


7.5 Arrange the following alkenes in order of decreasing stability.

1-Pentene, *cis*-2-pentene, *trans*-2-pentene, 2-methyl-2-butene



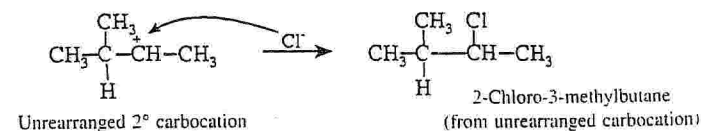
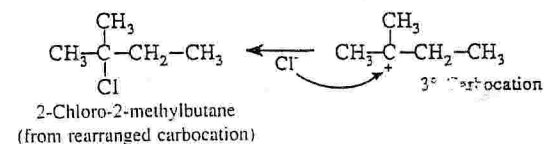
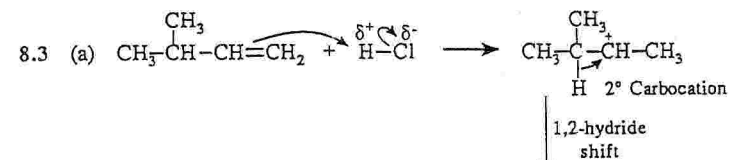
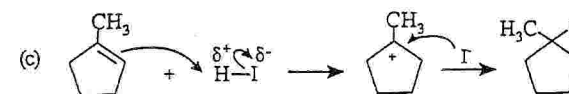
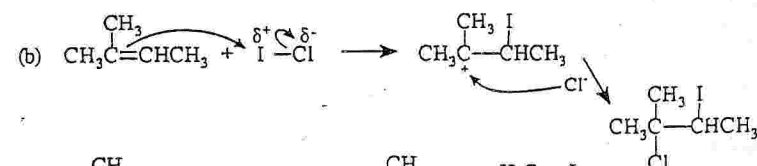
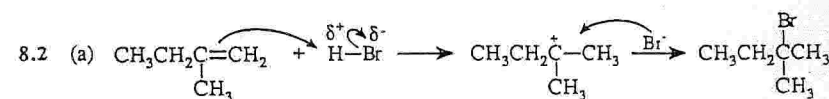
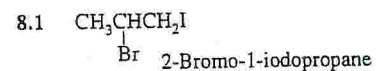
7.6 Complete the following synthesis.



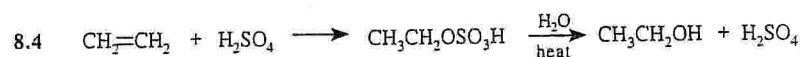
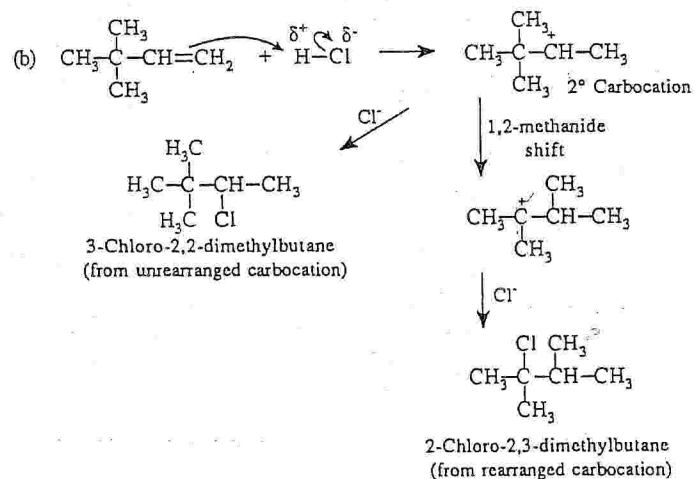
## 8

ALKENES AND ALKYNES II:  
ADDITION REACTIONS

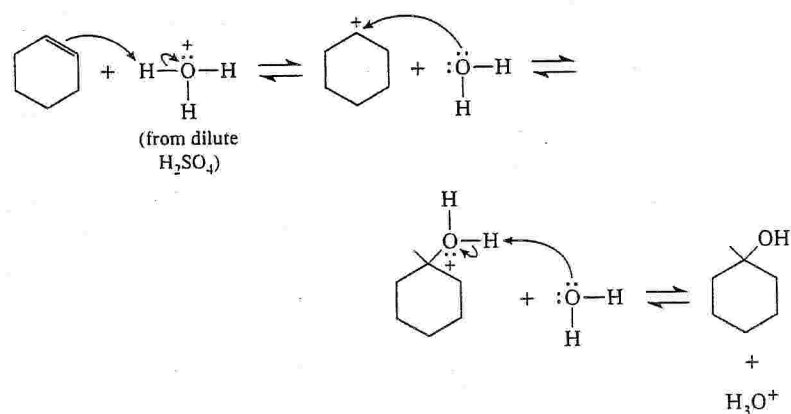
## SOLUTIONS TO PROBLEMS





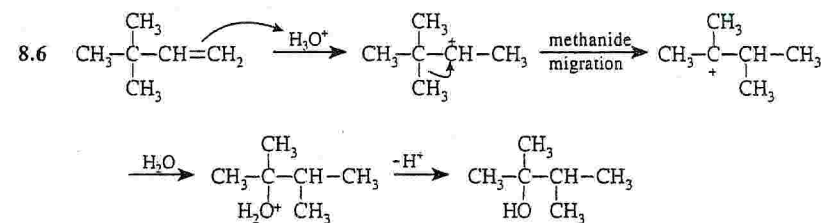
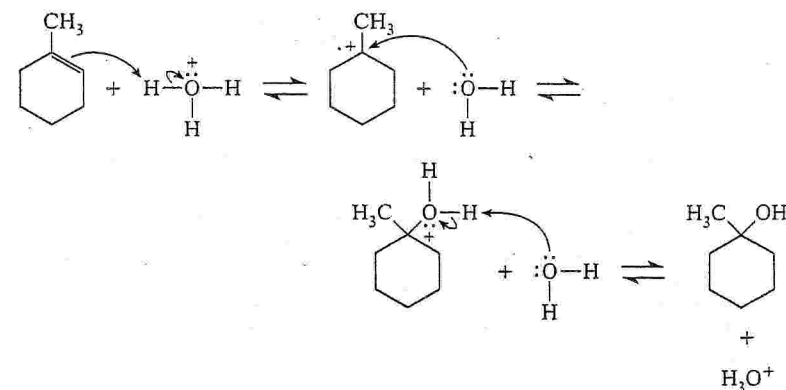


- 8.5 (a) Use a high concentration of water because we want the carbocation produced to react with water. And use a strong acid whose conjugate base is a very weak nucleophile. (For this reason we would not use HI, HBr, or HCl.) An excellent method, therefore, is to use dilute sulfuric acid.

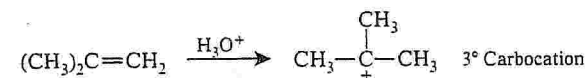


- (b) Use a low concentration of water (i.e., use concentrated  $\text{H}_2\text{SO}_4$ ) and use a higher temperature to encourage elimination.

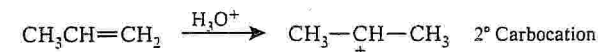
- (c) 1-Methylcyclohexanol would be the product because a 3° carbocation would be formed as the intermediate.



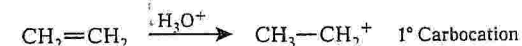
- 8.7 The order reflects the relative ease with which these alkenes accept a proton and form a carbocation.  $(\text{CH}_3)_2\text{C}=\text{CH}_2$  reacts faster because it leads to a tertiary cation.



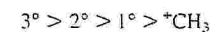
$\text{CH}_3\text{CH}=\text{CH}_2$  leads to a secondary cation.

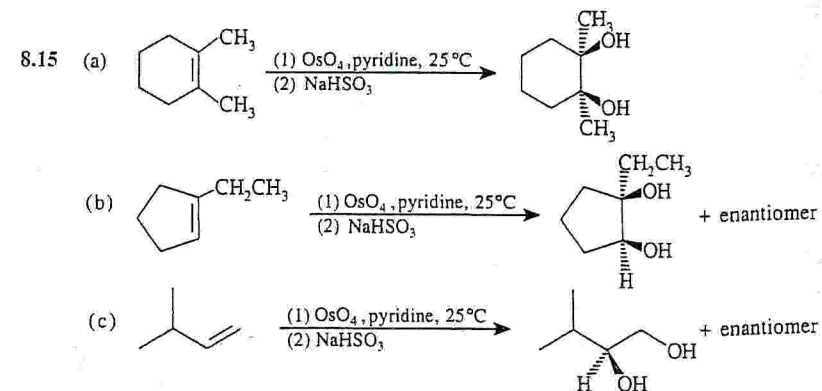
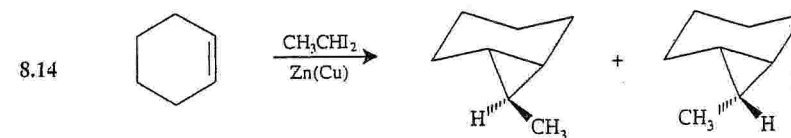
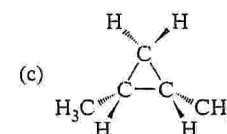
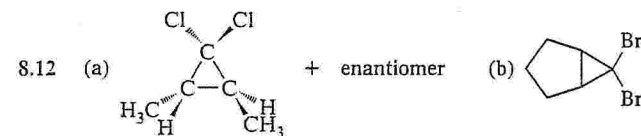
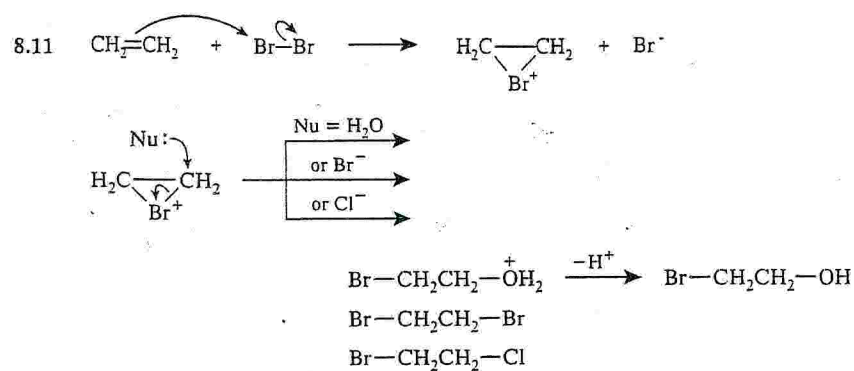
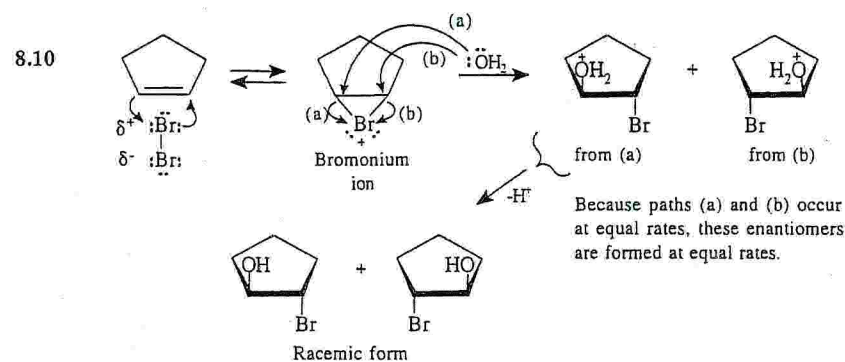
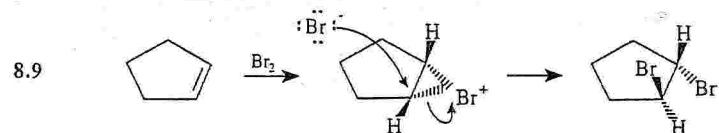
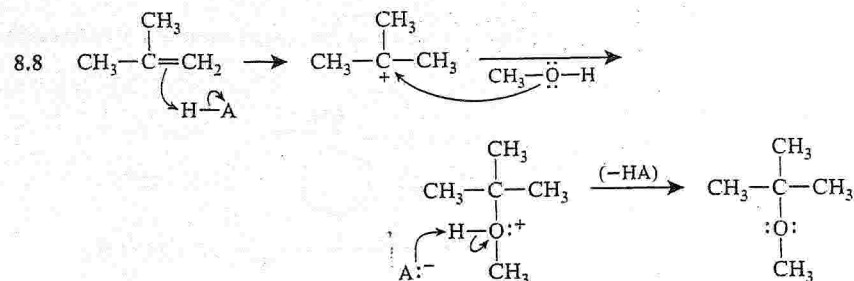


and  $\text{CH}_2=\text{CH}_2$  reacts most slowly because it leads to a primary carbocation.

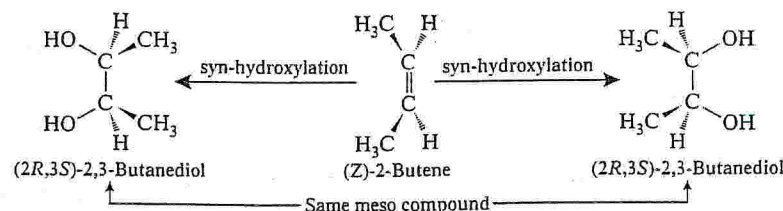


Recall that formation of the carbocation is the rate-determining step in acid-catalyzed hydration and that the order of stabilities of carbocations is the following:

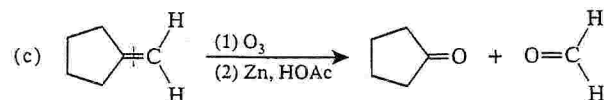
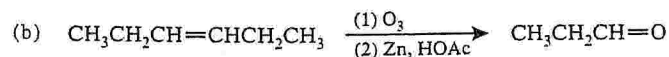
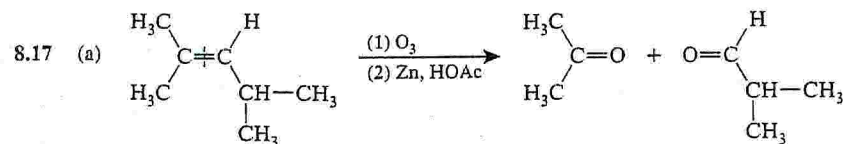
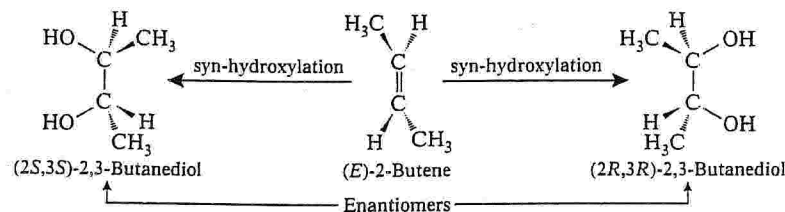




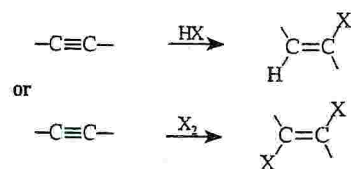
- 8.16 (a) Syn-hydroxylation at either face of (*Z*)- or cis-alkene leads to the meso compound (2*R*,3*S*)-2,3-butanediol.



- (b) Syn-hydroxylation at one face of the (*E*)- or trans-alkene leads to the (2*R*,3*R*)-enantiomer; at the other face, which is equally likely, it leads to the (2*S*,3*S*)-enantiomer.



- 8.18 Ordinary alkenes are more reactive toward electrophilic reagents. But the alkenes obtained from the addition of an electrophilic reagent to an alkyne have at least one electronegative atom (Cl, Br, etc.) attached to a carbon atom of the double bond.



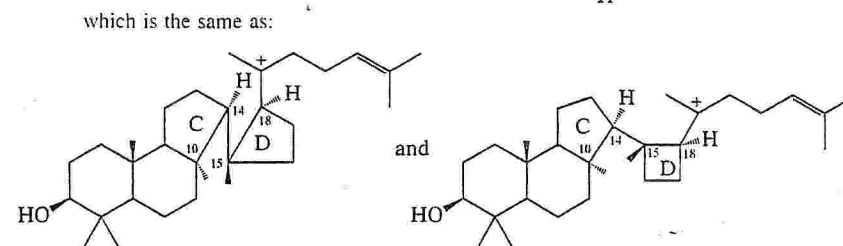
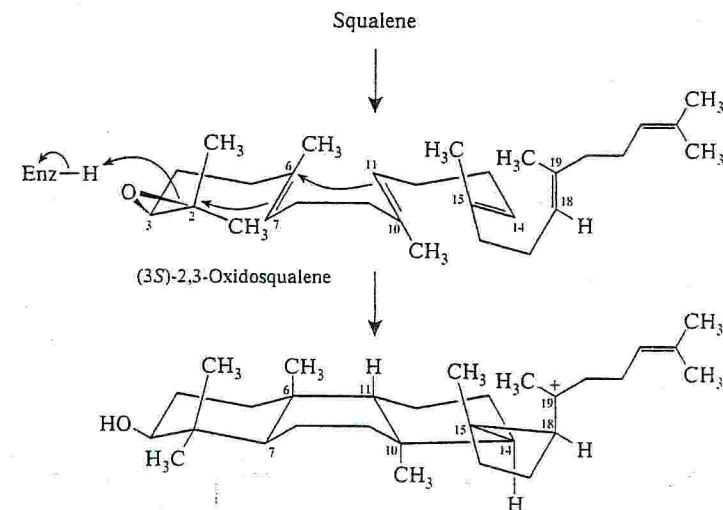
These alkenes are less reactive than alkynes toward electrophilic addition because the electronegative group makes the double bond "electron poor."

- 8.19 The molecular formula and the formation of octane from A and B indicate that both compounds are unbranched octynes. Since A yields only  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$  on ozonolysis, A must be the symmetrical octyne  $\text{CH}_3\text{CH}_2\text{CH}_2\text{C}\equiv\text{CCH}_2\text{CH}_2\text{CH}_3$ . The IR absorption for B shows the presence of a terminal triple bond. Hence B is  $\text{CH}_3(\text{CH}_2)_5\text{C}\equiv\text{CH}$ .

Since C ( $\text{C}_8\text{H}_{12}$ ) gives  $\text{HO}_2\text{C}(\text{CH}_2)_6\text{CO}_2\text{H}$  on ozonolysis, C must be cyclooctyne. This is supported by the molecular formula of C and the fact that it is converted to  $\text{C}_8\text{H}_{16}$  (cyclooctane) on catalytic hydrogenation.

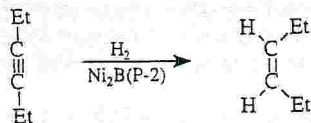
Answer to the Study Problem related to cholesterol biosynthesis, page 355.

In cholesterol biosynthesis an anti-Markovnikov addition occurs between C10 (once it becomes like a tertiary carbocation) and C15, forming the six-membered "C" ring of cholesterol (see the reactions in the text, page 355). This process results in a developing secondary carbocation at C14, which adds to C18 to form the five-membered "D" ring of cholesterol. If, on the other hand, Markovnikov addition occurred between C10 and C14 instead of anti-Markovnikov addition between C10 and C15, as shown in the following scheme, a developing tertiary carbocation would result at C15, along with formation of a five-membered "C" ring. Then, Markovnikov addition of C15 (as it becomes like a tertiary carbocation) to C18 would lead to a four-membered "D" ring and a tertiary carbocation at C19.

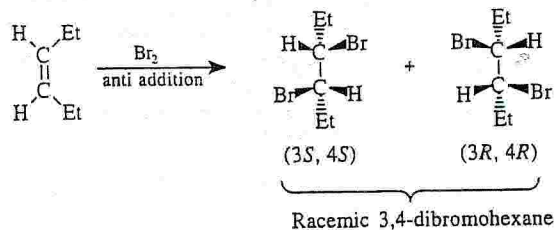




8.20 By converting the 3-hexyne to *cis*-3-hexene using  $H_2/Ni_2B(P-2)$ .

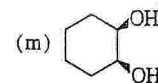


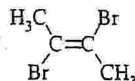
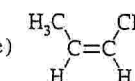
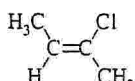
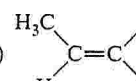
Then, addition of bromine to *cis*-3-hexene will yield (3*R*,4*R*), and (3*S*,4*S*)-3,4-dibromohexane as a racemic form.



- 8.21 (a)  $\text{CH}_3\text{CH}_2\text{CH}(\text{I})\text{CH}_3$  (b)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$  (c)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$   
 (d)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OSO}_3\text{H})\text{CH}_3$  (e)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$  (f)  $\text{CH}_3\text{CH}_2\text{CH}(\text{Br})\text{CH}_3$   
 (g)  $\text{CH}_3\text{CH}_2\text{CH}(\text{Br})\text{CH}_2\text{Br}$  (h)  $\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$  (i)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{Br}$   
 (j)  $\text{CH}_3\text{CH}_2\text{CH}(\text{Cl})\text{CH}_3$  (k)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$  (l)  $\text{CH}_3\text{CH}_2\text{CHO} + \text{HCHO}$   
 (m)  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$  (n)  $\text{CH}_3\text{CH}_2\text{CO}_2\text{H} + \text{CO}_2$

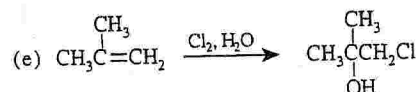
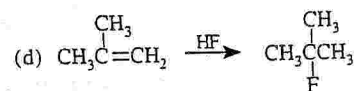
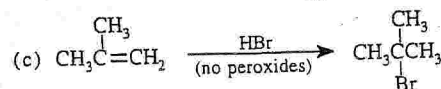
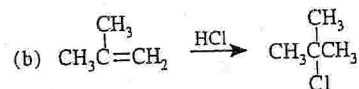
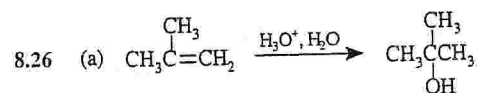
- 8.22 (a)  (b)  (c)   
 (d)  (e)  (f)   
 (g)  + enantiomer (h)  (i)  + enantiomer  
 (j)  (k)  (l)  $\text{HC}(\text{O})(\text{CH}_2)_4\text{CHO}$



- 8.23 (a)  $\text{CH}_3\text{CH}_2\text{C}(\text{Br})=\text{CHBr}$  (b)  $\text{CH}_3\text{CH}_2\text{C}(\text{Br})=\text{CH}_2$  (c)  $\text{CH}_3\text{CH}_2\text{CBr}_2\text{CH}_3$   
 (d)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$  (e)  $\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$  (f)  $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CCH}_3$   
 (g)  $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$  and  $\text{CH}_2=\text{C}(\text{CH}_3)_2$  [An E2 reaction would take place when  $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CNa}$  is treated with  $(\text{CH}_3)_3\text{CBr}$ .]  
 8.24 (a)  $\text{CH}_3\text{C}(\text{Br})=\text{CHCH}_3$  (b)  $\text{CH}_3\text{CBr}_2\text{CH}_2\text{CH}_3$  (c)   
 (d)  $\text{CH}_3\text{CBr}_2\text{CHBrCH}_3$  (e)  (f)   
 (g)  (h)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$  (i)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$   
 (j)  $\text{CH}_3\text{CO}_2\text{H}$  (2 molar equivalents) (k)  $\text{CH}_3\text{CO}_2\text{H}$  (2 molar equivalents)  
 (l) no reaction

- 8.25 (a)  $\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2 \xrightarrow[\text{CCl}_4]{Br_2} \text{CH}_3\text{CH}_2\text{CH}(\text{Br})\text{CH}_2\text{Br} \xrightarrow[\text{heat}]{3\text{NaNH}_2, \text{mineral oil}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$   
 $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CNa} \xrightarrow{\text{NH}_4\text{Cl}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$   
 (b)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl} \xrightarrow[\text{heat}]{t\text{-BuOK, } t\text{-BuOH}} \text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$  Then as in (a)  
 (c)  $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCl} \xrightarrow[\text{heat}]{2\text{NaNH}_2, \text{mineral oil}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CNa} \xrightarrow{\text{NH}_4\text{Cl}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$   
 (d)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}(\text{Cl})\text{CH}_2\text{Cl} \xrightarrow[\text{heat}]{3\text{NaNH}_2, \text{mineral oil}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CNa} \xrightarrow{\text{NH}_4\text{Cl}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$   
 (e)  $\text{H}-\text{C}\equiv\text{C}-\text{H} \xrightarrow[\text{liq. NH}_3]{\text{NaNH}_2} \text{H}-\text{C}\equiv\text{CNa} \xrightarrow{\text{CH}_3\text{CH}_2\text{Br}} \text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$

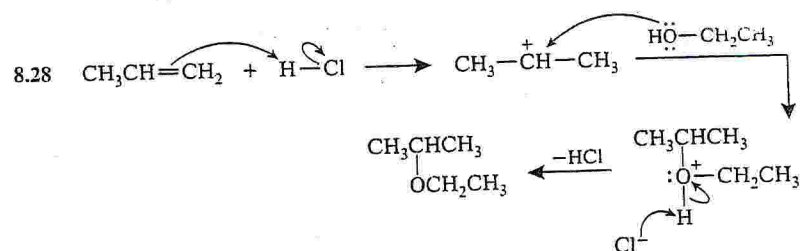
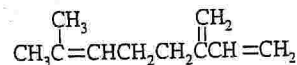




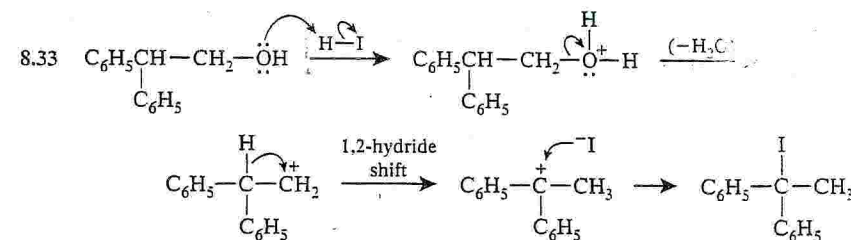
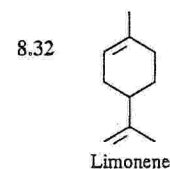
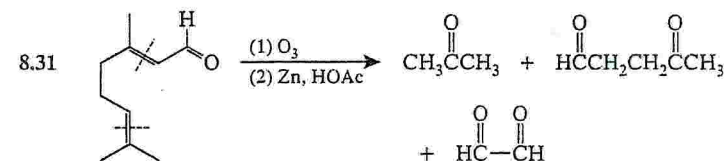
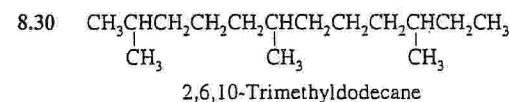
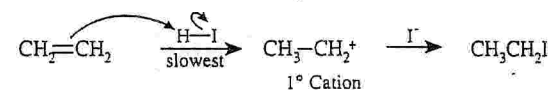
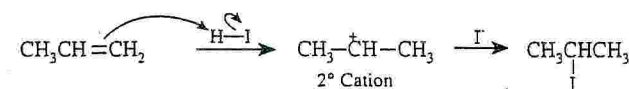
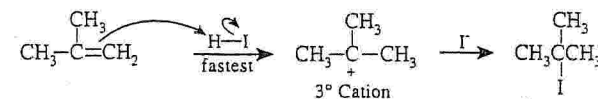
- 8.27 (a)  $\text{C}_{10}\text{H}_{22}$  (saturated alkane)  
 $\text{C}_{10}\text{H}_{16}$  (formula of myrcene)  
 $\text{H}_6 = 3$  pairs of hydrogen atoms

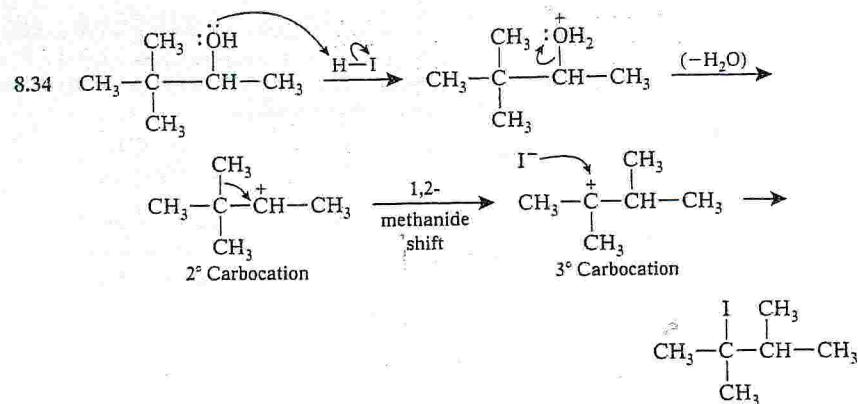
Index of hydrogen deficiency (IHD) = 3

- (b) Myrcene contains no rings because complete hydrogenation gives  $\text{C}_{10}\text{H}_{22}$ , which corresponds to an alkane.  
 (c) That myrcene absorbs three molar equivalents of  $\text{H}_2$  on hydrogenation indicates that it contains three double bonds.  
 (d) Three structures are possible; however, only one gives 2,6-dimethyloctane on complete hydrogenation. Myrcene is therefore

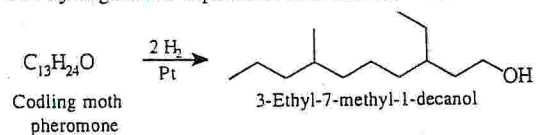


- 8.29 The rate-determining step in each reaction is the formation of a carbocation when the alkene accepts a proton from HI. When 2-methylpropene reacts, it forms a  $3^\circ$  carbocation (the most stable); therefore, it reacts fastest. When ethene reacts, it forms a  $1^\circ$  carbocation (the least stable); therefore, it reacts the slowest.

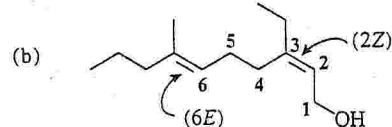
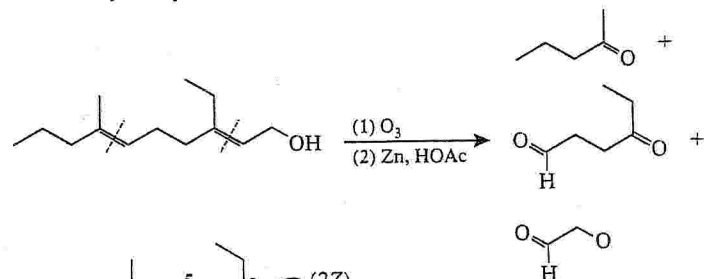




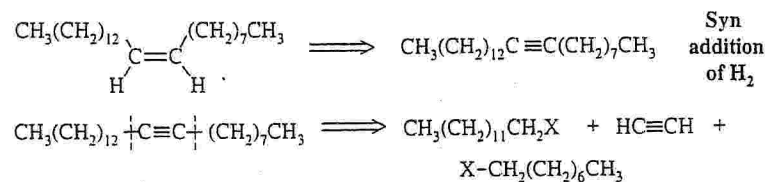
- 8.35 (a) The hydrogenation experiment discloses the carbon skeleton of the pheromone.



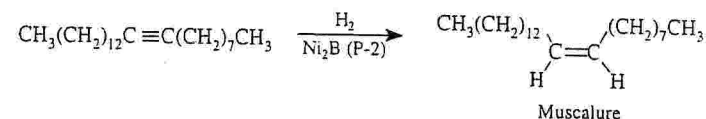
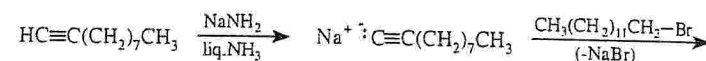
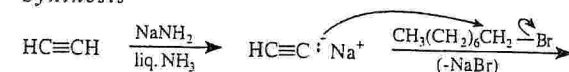
The ozonolysis experiment allows us to locate the position of the double bonds.



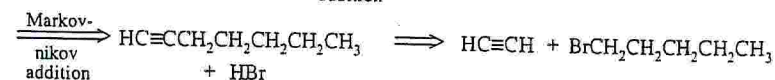
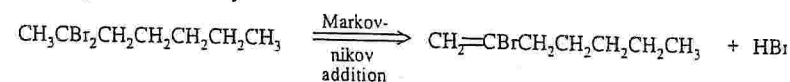
- 8.36 Retrosynthetic analysis



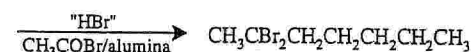
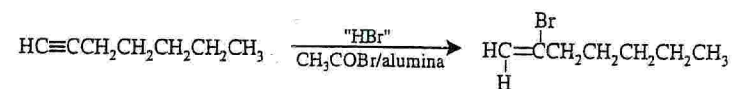
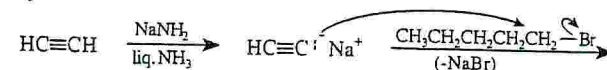
### Synthesis



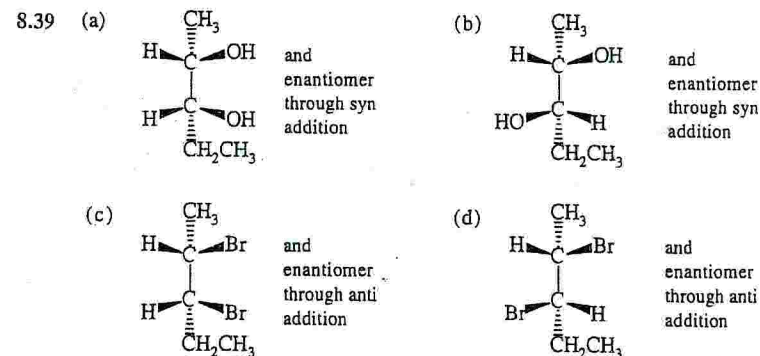
- \*8.37 Retrosynthetic analysis



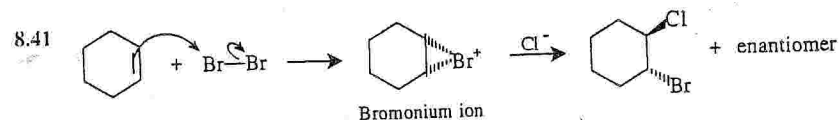
### Synthesis



- 8.38 Syn hydrogenation of the triple bond is required. So use  $H_2$  and  $Ni_2B(P-2)$  or  $H_2$  and Lindlar's catalyst.



- 8.40 (a) (2*S*,3*R*)- [the enantiomer is (2*R*,3*S*)-]  
 (b) (2*S*,3*S*)- [the enantiomer is (2*R*,3*R*)-]  
 (c) (2*S*,3*R*)- [the enantiomer is (2*R*,3*S*)-]  
 (d) (2*S*,3*S*)- [the enantiomer is (2*R*,3*R*)-]



The bromonium ion reacts with a chloride ion to produce the *trans*-1-bromo-2-chlorocyclohexane enantiomers.

- 8.42 (a) 1-Pentyne has IR absorption at about  $3300\text{ cm}^{-1}$  due to its terminal triple bond. Pentane does not absorb in that region.  
 (b) 1-Pentene absorbs in the  $1620\text{--}1680\text{ cm}^{-1}$  region due to the alkene function. Pentane does not exhibit absorption in that region.  
 (c) See parts (a) and (b).  
 (d) 1-Bromopentane shows C-Br absorption in the  $690\text{--}515\text{ cm}^{-1}$  region while pentane does not.  
 (e) For 1-pentyne, see (a). The interior triple bond of 2-pentyne gives relatively weak absorption in the  $2100\text{--}2260\text{ cm}^{-1}$  region.  
 (f) For 1-pentene, see (b). 1-Pentanol has a broad absorption band in the  $3200\text{--}3550\text{ cm}^{-1}$  region.  
 (g) See (f).  
 (h) 1-Bromo-2-pentene has double bond absorption in the  $1620\text{--}1680\text{ cm}^{-1}$  region which 1-bromopentane lacks.  
 (i) 2-Penten-1-ol has double bond absorption in the  $1620\text{--}1680\text{ cm}^{-1}$  region not found in 1-pentanol.

- 8.43 Because of the electron-withdrawing nature of chlorine, the electron density at the double bond is greatly reduced and attack by the electrophilic bromine does not occur.

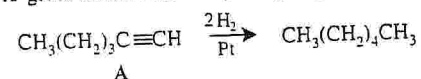
- \*8.44 The index of hydrogen deficiency of A, B, and C is two.

$$\begin{array}{l} \text{C}_6\text{H}_{14} \\ \text{C}_6\text{H}_{10} \\ \text{H}_4 = 2 \text{ pairs of hydrogen atoms} \end{array}$$

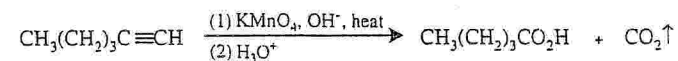
This result suggests the presence of a triple bond, two double bonds, a double bond and a ring, or two rings. The fact that A, B, and C all decolorize  $\text{Br}_2/\text{CCl}_4$  and dissolve in concd.  $\text{H}_2\text{SO}_4$  suggests they all have a carbon-carbon multiple bond.

A must be a terminal alkyne, because of IR absorption at about  $3300\text{ cm}^{-1}$ .

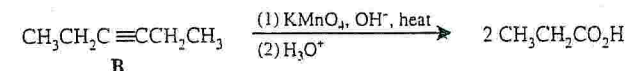
Since A gives hexane on catalytic hydrogenation, A must be 1-hexyne.



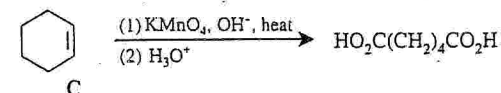
This is confirmed by the oxidation experiment



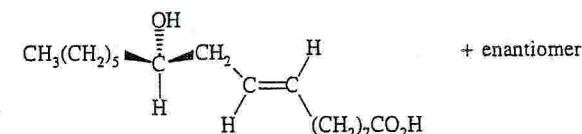
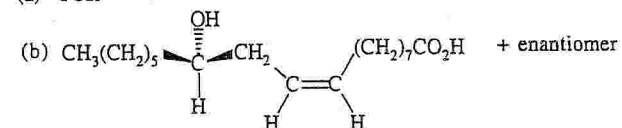
Hydrogenation of B to hexane shows that its chain is unbranched, and the oxidation experiment shows that B is 3-hexyne.



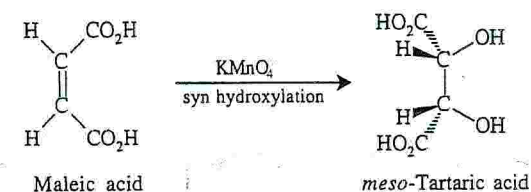
Oxidation of C shows that it is cyclohexene.



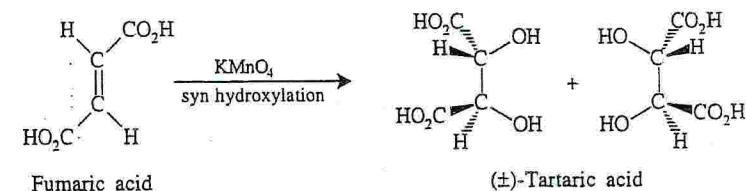
- 8.45 (a) Four



- 8.46 Hydroxylations by  $\text{KMnO}_4$  are syn hydroxylations (cf. Section 8.9). Thus, maleic acid must be the *cis*-dicarboxylic acid:

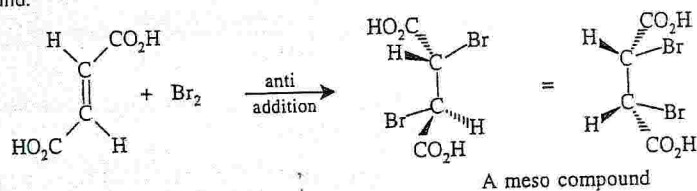


Fumaric acid must be the *trans*-dicarboxylic acid:

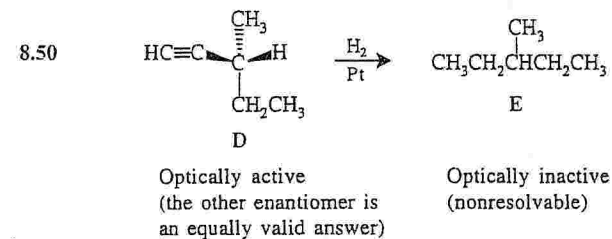
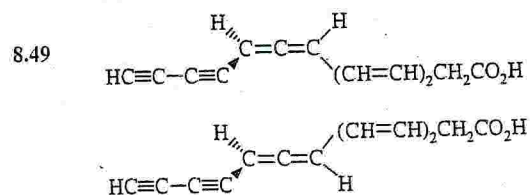
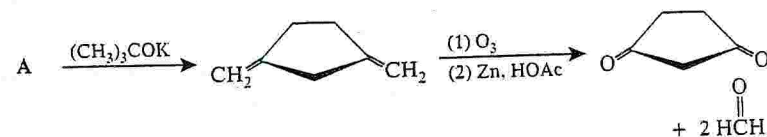
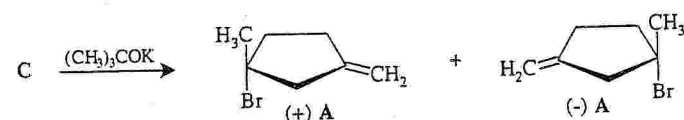
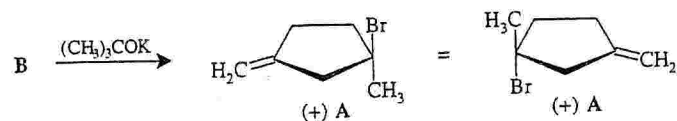
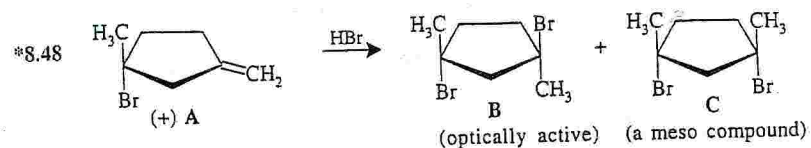




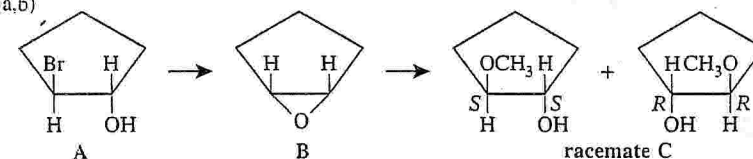
- 8.47 (a) The addition of bromine is an anti addition. Thus, fumaric acid yields a meso compound.



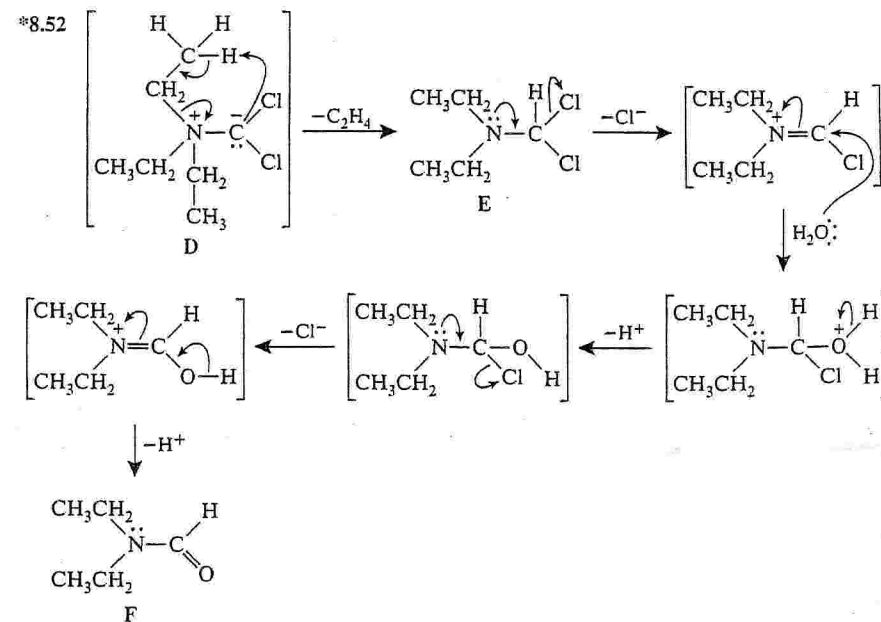
- (b) Maleic acid adds bromine to yield a racemic modification.



- \*8.51 (a,b)



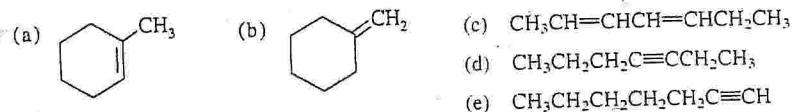
- (c) C, in contrast to its *cis* isomer, would exhibit no intramolecular hydrogen-bonding. This would be proven by the absence of infrared absorption in the 3500- to 3600- $\text{cm}^{-1}$  region when studied as a very dilute solution in  $\text{CCl}_4$ . C would only show free O—H stretch at about 3625  $\text{cm}^{-1}$ .

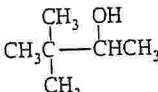


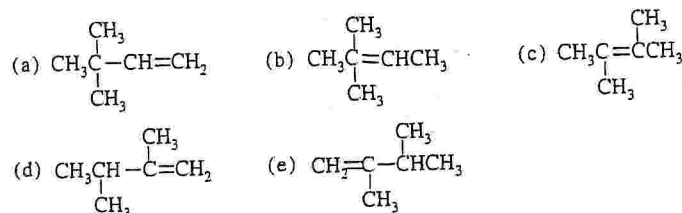


## QUIZ

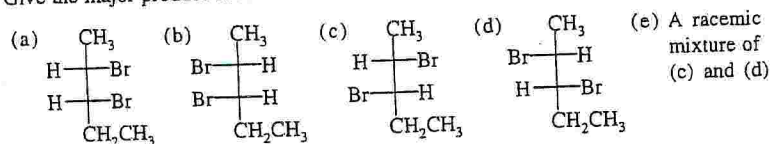
- 8.1 A hydrocarbon whose molecular formula is  $C_7H_{12}$ , on catalytic hydrogenation (excess  $H_2/Pt$ ), yields  $C_7H_{16}$ . The original hydrocarbon adds bromine and also exhibits an IR absorption band at  $3300\text{ cm}^{-1}$ . Which of the following is a plausible choice of structure for the original hydrocarbon?



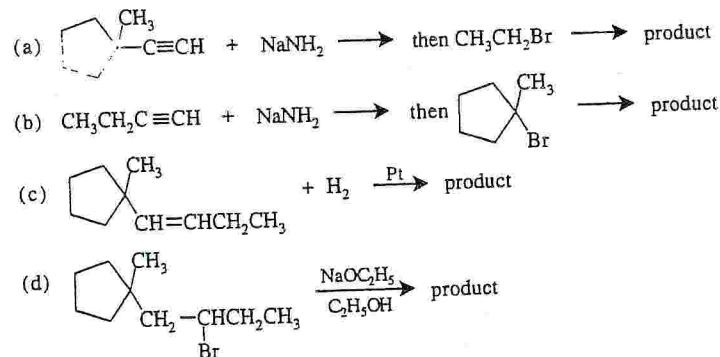
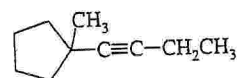
- 8.2 Select the major product of the dehydration of the alcohol, 



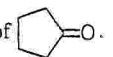
- 8.3 Give the major product of the reaction of *cis*-2-pentene with bromine.

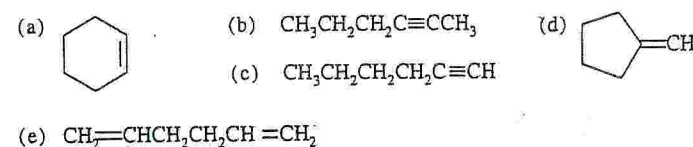


- 8.4 The compound shown here is best prepared by which sequence of reactions?



- 8.5 A compound whose formula is  $C_6H_{10}$  (Compound A) reacts with  $H_2/Pt$  in excess to give a product  $C_6H_{12}$ , which does not decolorize  $Br_2/CCl_4$ . Compound A does not show IR absorption in the  $3200\text{--}3400\text{ cm}^{-1}$  region.

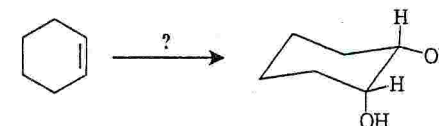
Ozonolysis of A gives 1 mol of  $HCHO$  and 1 mol of . Give the structure of A.



- 8.6 Compound B ( $C_5H_{10}$ ) does not dissolve in cold, concentrated  $H_2SO_4$ . What is B?

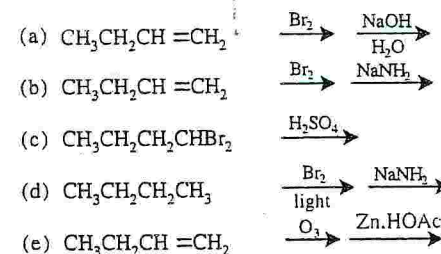


- 8.7 Which reaction sequence converts cyclohexene to *cis*-1,2-cyclohexanediol? That is,



- (a) Cold, dilute, aqueous  $KMnO_4$ ,  $OH^-$  (b) (1)  $O_3$  (2)  $Zn/HOAc$   
 (c) (1)  $OsO_4$  (2)  $NaHSO_3$  (d) (1)  $RC(=O)OOH$  (2)  $H_3O^+/H_2O$   
 (e) More than one of these

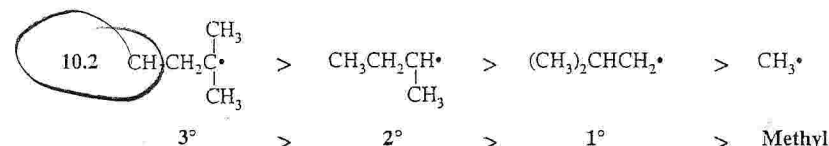
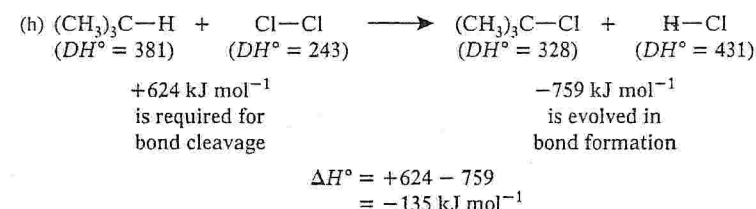
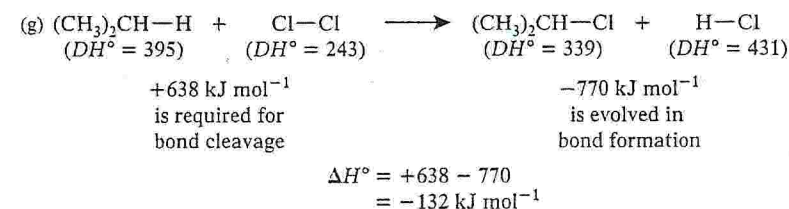
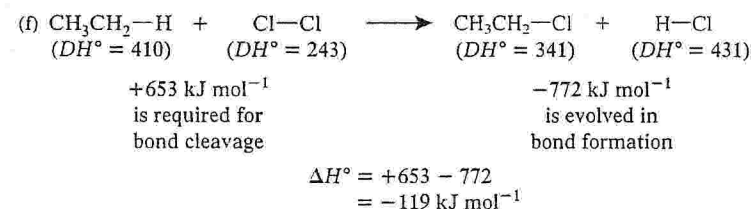
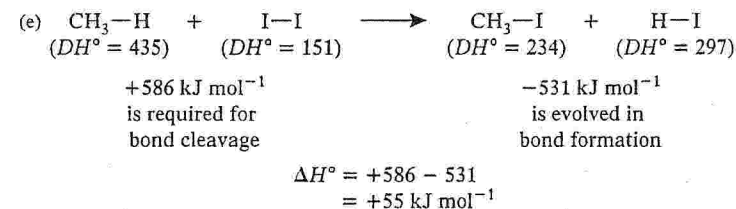
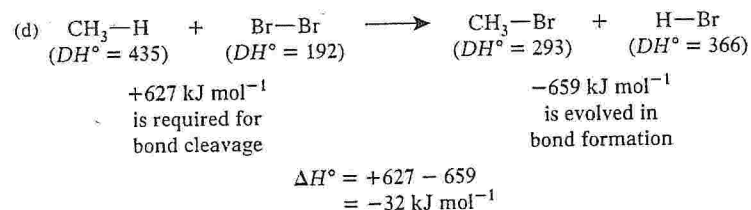
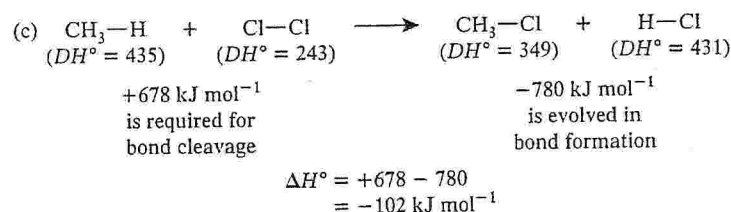
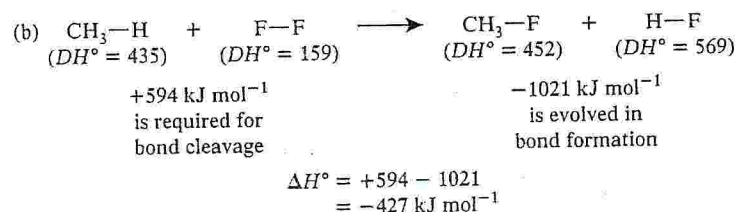
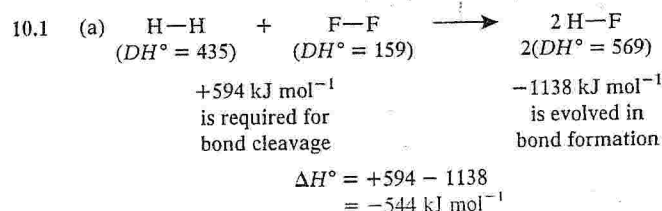
- 8.8 Which of the following sequences leads to the best synthesis of the compound  $CH_3CH_2C\equiv CH$ ? (Assume that the quantities of reagents are sufficient to carry out the desired reaction.)



# 10

## RADICAL REACTIONS

### SOLUTIONS TO PROBLEMS



10.3 The compounds all have different boiling points. They could, therefore, be separated by careful fractional distillation. Or, because the compounds have different vapor pressures, they could easily be separated by gas chromatography. GC/MS (gas chromatography/mass spectrometry) could be used to separate the compounds as well as provide structural information from their mass spectra. Their mass spectra would show contributions from the naturally occurring  $^{35}\text{Cl}$  and  $^{37}\text{Cl}$  isotopes. The natural abundance of

$^{35}\text{Cl}$  is approximately 75% and that of  $^{37}\text{Cl}$  is approximately 25%. Thus, for  $\text{CH}_3\text{Cl}$ , containing only one chlorine atom, there will be an  $\text{M}^+$  peak and an  $\text{M}^+ + 2$  peak in roughly a 3:1 (0.75:0.25) ratio of intensities. For  $\text{CH}_2\text{Cl}_2$  there will be  $\text{M}^+$ ,  $\text{M}^+ + 2$ , and  $\text{M}^+ + 4$  peaks in roughly a 9:6:1 ratio, respectively. [The probability of a molecular ion  $\text{M}^+$  with both chlorine atoms as  $^{35}\text{Cl}$  is  $(.75)(.75) = .56$ , the probability of an  $\text{M}^+ + 2$  ion from one  $^{35}\text{Cl}$  and one  $^{37}\text{Cl}$  is  $2(.75)(.25) = .38$ , and the probability of an  $\text{M}^+ + 4$  ion peak from both chlorine atoms as  $^{37}\text{Cl}$  is  $(.25)(.25) = 0.06$ ; thus, their ratio is 9:6:1.] For  $\text{CHCl}_3$  there will be  $\text{M}^+$ ,  $\text{M}^+ + 2$ , and  $\text{M}^+ + 4$ , and  $\text{M}^+ + 6$  peaks in approximately a 27:27:9:1 ratio, respectively (based on a calculation by the same method). (This calculation does not take into account the contribution of  $^{13}\text{C}$ ,  $^2\text{H}$ , and other isotopes, but these are much less abundant.)

- 10.4 A small amount of ethane is formed by the combination of two methyl radicals:

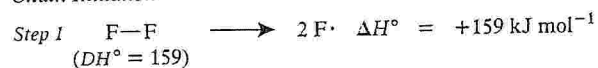


This ethane then reacts with chlorine in a substitution reaction (see Section 10.6) to form chloroethane.

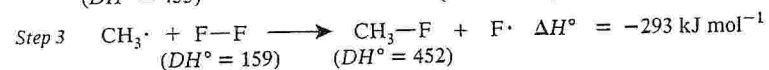
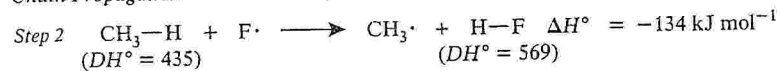
The significance of this observation is that it is evidence for the proposal that the combination of methyl radicals is one of the chain-terminating steps in the chlorination of methane.

- 10.5 The use of a large excess of chlorine allows all of the chlorinated methanes ( $\text{CH}_3\text{Cl}$ ,  $\text{CH}_2\text{Cl}_2$ , and  $\text{CHCl}_3$ ) to react with chlorine.

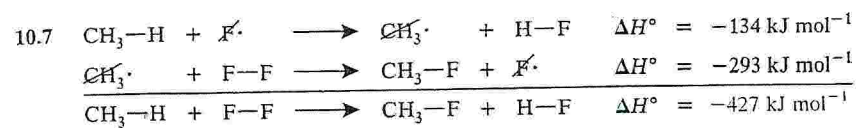
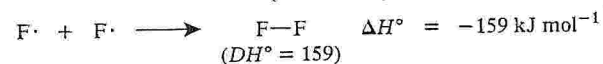
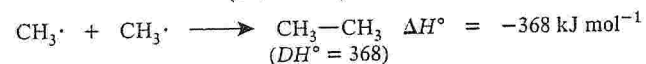
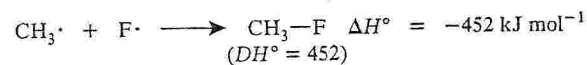
#### 10.6 Chain Initiation



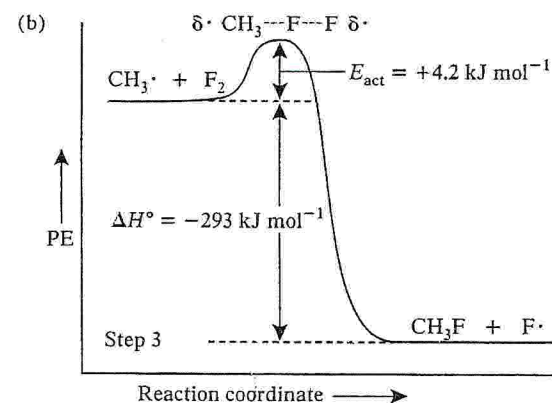
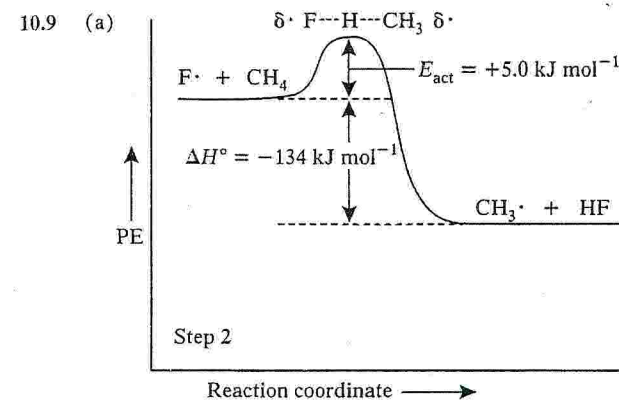
#### Chain Propagation



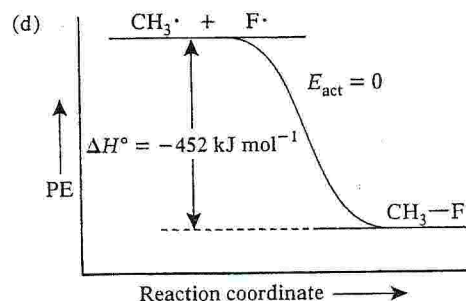
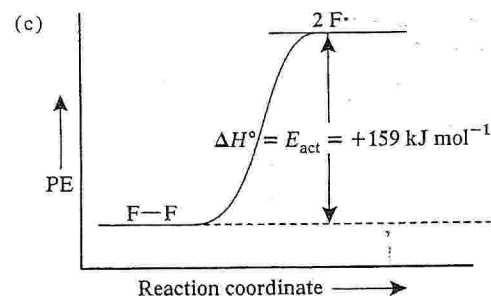
#### Chain Termination



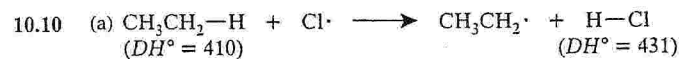
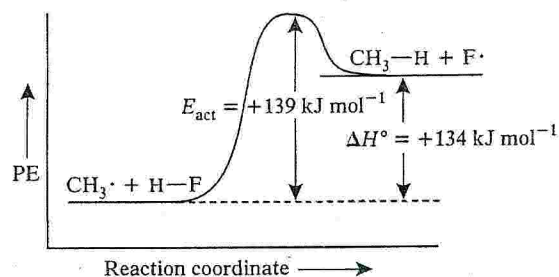
- 10.8 (a) Reactions (3), (5), and (6) should have  $E_{\text{act}} = 0$  because these are gas-phase reactions in which small radicals combine to form molecules.  
 (b) Reactions (1), (2), and (4) should have  $E_{\text{act}} > 0$  because in them covalent bonds are broken.  
 (c) Reactions (1) and (2) should have  $E_{\text{act}} = \Delta H^\circ$  because in them bonds are broken homolytically but no bonds are formed.



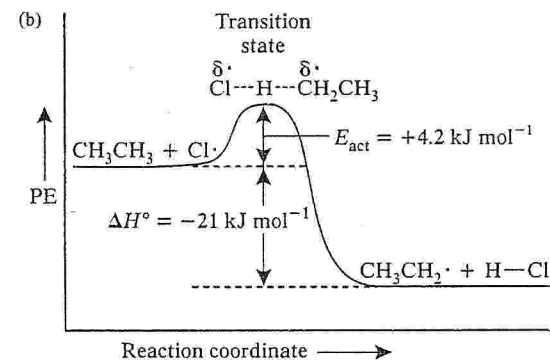




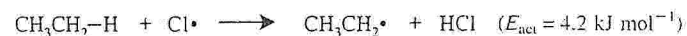
(e) Notice that this is the reverse of Step (2) in part (a)



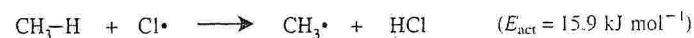
$$\Delta H^\circ = -431 + 410 = -21 \text{ kJ mol}^{-1}$$



(c) The hydrogen abstraction step for ethane,

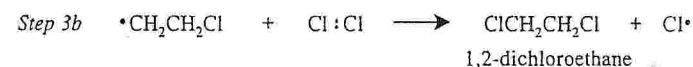
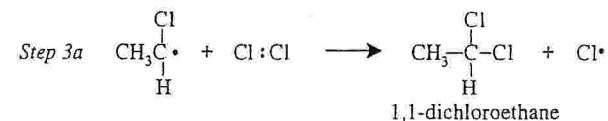
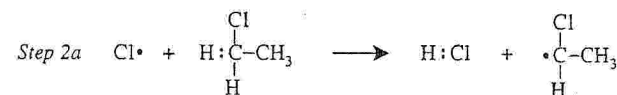
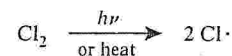


has a much lower energy of activation than the corresponding step for methane:

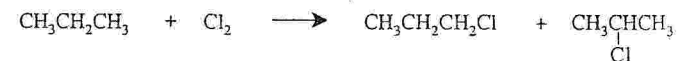


Therefore, ethyl radicals form much more rapidly in the mixture than methyl radicals, and this leads to the more rapid formation of ethyl chloride.

10.11



10.12 (a) There is a total of eight hydrogen atoms in propane. There are six equivalent 1° hydrogen atoms, replacement of any one of which leads to propyl chloride, and there are two equivalent 2° hydrogen atoms, replacement of any one of which leads to isopropyl chloride.



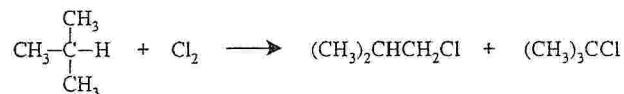


If all the hydrogen atoms were equally reactive, we would expect to obtain 75% propyl chloride and 25% isopropyl chloride:

$$\% \text{ Propyl chloride} = \frac{3}{4} \times 100 = 75\%$$

$$\% \text{ Isopropyl chloride} = \frac{1}{4} \times 100 = 25\%$$

- (b) Reasoning in the same way as in part (a), we would expect 90% isobutyl chloride and 10% *tert*-butyl chloride, if the hydrogen atoms were equally reactive.



$$\% \text{ Isobutyl chloride} = \frac{9}{10} \times 100 = 90\%$$

$$\% \text{ } \textit{tert}\text{-Butyl chloride} = \frac{1}{10} \times 100 = 10\%$$

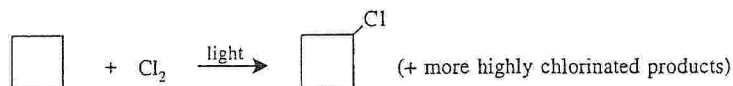
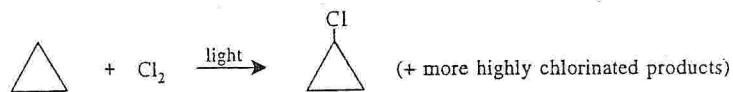
- (c) In the case of propane (see Section 10.6), we actually get more than twice as much isopropyl chloride (55%) than we would expect if the 1° and 2° hydrogen atoms were equally reactive (25%). Clearly, then, 2° hydrogen atoms are more than twice as reactive as 1° hydrogen atoms.

In the case of isobutane, we get almost four times as much *tert*-butyl chloride (37%) as we would get (10%) if the 1° and 3° hydrogen atoms were equally reactive.

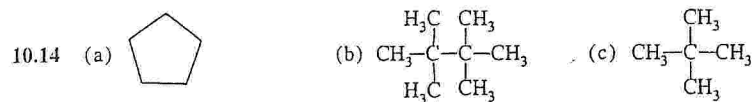
The order of reactivity of the hydrogens then must be

$$3^\circ > 2^\circ > 1^\circ$$

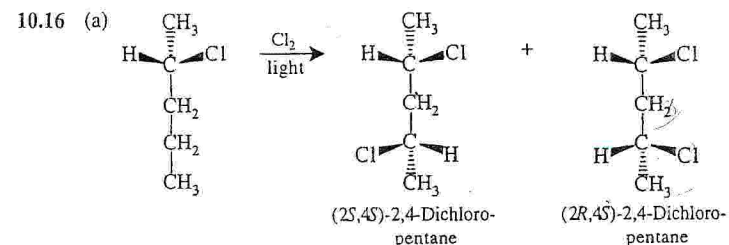
- 10.13 The hydrogen atoms of these molecules are all equivalent. Replacing any one of them yields the same product.



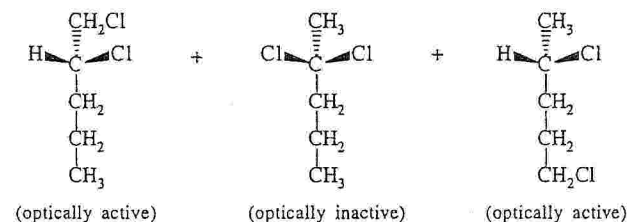
We can minimize the amounts of more highly chlorinated products formed by using a large excess of the cyclopropane or cyclobutane. (And we can recover the unreacted cyclopropane or cyclobutane after the reaction is over.)



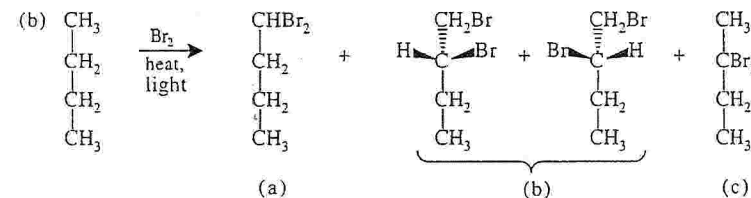
- 10.15 At lower temperatures, isomer distribution accurately reflects the inherent reactivities of the hydrogens of the alkanes. As the temperature is raised, chlorine atoms become more reactive, and hence less discriminating. If the temperature is high enough, hydrogens are replaced by chlorine on a purely statistical basis.

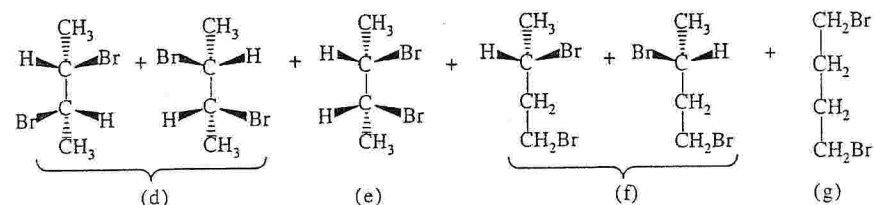


- (b) They are diastereomers. (They are stereoisomers, but they are not mirror images of each other.)  
 (c) No, (2*R*,4*S*)-2,4-dichloropentane is achiral because it is a meso compound. (It has a plane of symmetry passing through C3.)  
 (d) No, the achiral meso compound would not be optically active.  
 (e) Yes, by fractional distillation or by gas chromatography. (Diastereomers have different physical properties. Therefore, the two isomers would have different vapor pressures.)  
 (f and g) In addition to the (2*S*,4*S*)-2,4-dichloropentane and (2*R*,4*S*)-2,4-dichloropentane isomers described previously, we would also get (2*S*,3*S*)-2,3-dichloropentane, (2*S*,3*R*)-2,3-dichloropentane and the following:



- 10.17 (a) Seven (see below)



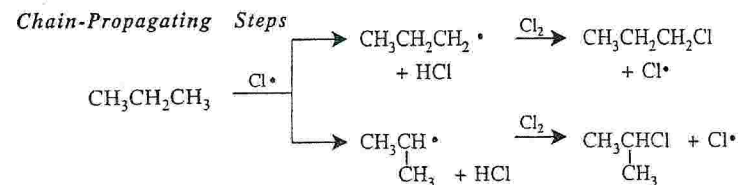
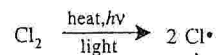


(c) None of the fractions would show optical activity. Fractions (b), (d), and (f) are racemic forms; all others contain achiral molecules.

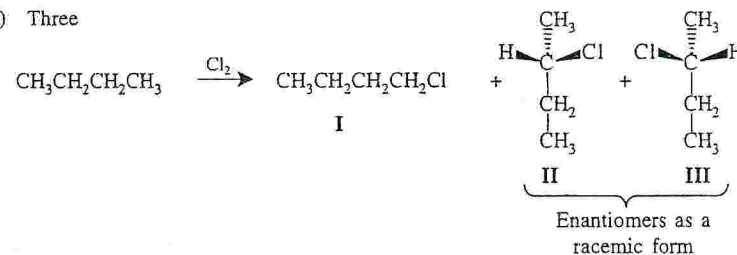
(d) Ions likely to be formed are the molecular ion ( $M^+$ ),  $M^+-Br$ , and others. The  $M^+$  peak would be accompanied by  $M^++2$  and  $M^++4$  peaks due to the isotopes of bromine. The natural abundance of  $^{79}Br$  is 50.5% and the natural abundance of  $^{81}Br$  is 49.5%. Thus, the  $M^+$  peak (where both bromines are  $^{79}Br$ ) has probability  $(.505)(.505) = .255$ , the  $M^++2$  peak (one  $^{79}Br$  and one  $^{81}Br$ ) has probability  $2(.495)(.505) = .500$ , and the probability of the  $M^++4$  peak (where both bromine atoms are  $^{81}Br$ ) is  $(.495)(.495) = .245$ . Thus, the  $M^+$ ,  $M^++2$ , and  $M^++4$  peaks will have an intensity ratio of approximately 1:2:1, respectively. (This calculation does not take into account the contribution of  $^{13}C$ ,  $^2H$ , and other isotopes.) The  $M^+-Br$  peak would also be accompanied by an  $M^+-Br+2$  peak.

- 10.18 (a) No, the only fractions that would contain chiral molecules (as enantiomers) would be those containing 1-chloro-2-methylbutane and the one containing 2-chloro-3-methylbutane. These fractions would not show optical activity, however, because they would contain racemic forms of the enantiomers.
- (b) Yes, the fractions containing 1-chloro-2-methylbutane and the one containing 2-chloro-3-methylbutane.
- (c) Yes, each fraction from the distillation could be identified on the basis of  $^1H$  NMR spectroscopy. The signals related to the carbons where the chlorine atom is bonded would be sufficient to distinguish them. The protons at C1 of 1-chloro-2-methylbutane would be a doublet due to splitting from the single hydrogen at C2. There would be no proton signal for C2 of 2-chloro-2-methylbutane since there are no hydrogens bonded at C2 in this compound; however, there would be a strong singlet for the six hydrogens of the geminal methyl groups. The protons at C2 of 2-chloro-3-methylbutane would approximately be a pentet, due to combined splitting from the three hydrogens at C1 and the single hydrogen at C3. The protons at C1 of 1-chloro-3-methylbutane would be a triplet due to splitting by the two hydrogens at C2.

#### 10.19 Chain-Initiating Step

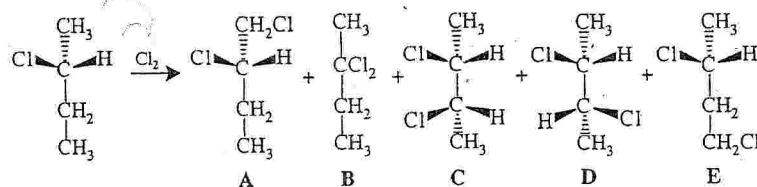


\*10.20 (a) Three



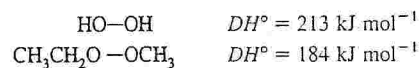
- (b) Only two: one fraction containing I, and another fraction containing the enantiomers II and III as a racemic form. (The enantiomers, having the same boiling points, would distill in the same fraction.)
- (c) Both of them.
- (d) The fraction containing the enantiomers.
- (e) The  $^1H$  spectrum for 1-chlorobutane would show a triplet at approximately  $\delta 3.6$ - $3.8$ , whereas the hydrogens at C2 of 2-chlorobutane (either enantiomer) would approximately be a pentet at  $\delta 3.6$ - $3.8$ . The DEPT spectra for 1-chlorobutane would have three positive signals corresponding to the carbons of the three  $CH_2$  groups and one negative signal corresponding to the  $CH_3$ . The DEPT spectra for the 2-chlorobutane enantiomers would have only one positive signal corresponding to the single  $CH_2$  carbon, and three negative signals corresponding to the two  $CH_3$  groups and the  $CH$  carbon.
- (f) Molecular ions from both 1-chlorobutane and the 2-chlorobutane enantiomers would be present (but probably of different intensities).  $M^++2$  peaks would also be present. Both compounds would likely undergo C-Cl bond cleavage to yield  $C_4H_9^+$  cations. The mass spectrum of 1-chlorobutane would probably show loss of a propyl radical by C-C bond cleavage adjacent to the chlorine, resulting in an  $m/z$  49 peak for  $CH_2Cl^+$  (and  $m/z$  51 from  $^{37}Cl$ ). Similar fragmentation in 2-chlorobutane would produce an  $m/z$  63 peak for  $CH_3CHCl^+$  (and  $m/z$  65).

10.21 (a) Five

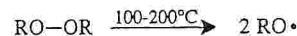


- (b) Five. None of the fractions would be a racemic form.
- (c) The fractions containing A, D, and E. The fraction containing B and C would be optically inactive. (B contains no stereocenter and C is a meso compound.)

10.22 (a) Oxygen-oxygen bonds are especially weak, that is,



This means that a peroxide will dissociate into radicals at a relatively low temperature.



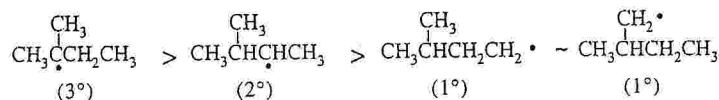
Oxygen-hydrogen single bonds, on the other hand, are very strong. (For HO-H,  $\Delta H^\circ = 498 \text{ kJ mol}^{-1}$ .) This means that reactions like the following will be highly exothermic.



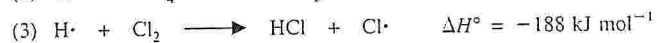
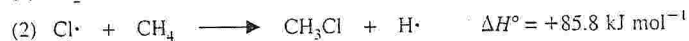
- $$\begin{array}{lcl}
 \text{(b) Step 1} & (\text{CH}_3)_3\text{CO}-\text{OC}(\text{CH}_3)_3 \xrightarrow{\text{heat}} 2 (\text{CH}_3)_3\text{CO}\cdot & \left. \begin{array}{l} \text{Chain} \\ \text{Initiation} \end{array} \right\} \\
 \text{Step 2} & (\text{CH}_3)_3\text{CO}\cdot + \text{R}-\text{H} \longrightarrow (\text{CH}_3)_3\text{COH} + \text{R}\cdot & \\
 \text{Step 3} & \text{R}\cdot + \text{Cl}-\text{Cl} \longrightarrow \text{R}-\text{Cl} + \text{Cl}\cdot & \left. \begin{array}{l} \text{Chain} \\ \text{Propagation} \end{array} \right\} \\
 \text{Step 4} & \text{Cl}\cdot + \text{R}-\text{H} \longrightarrow \text{H}-\text{Cl} + \text{R}\cdot & 
 \end{array}$$



## 10.23



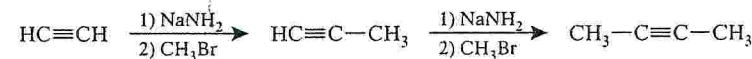
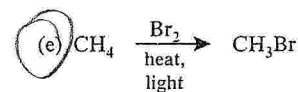
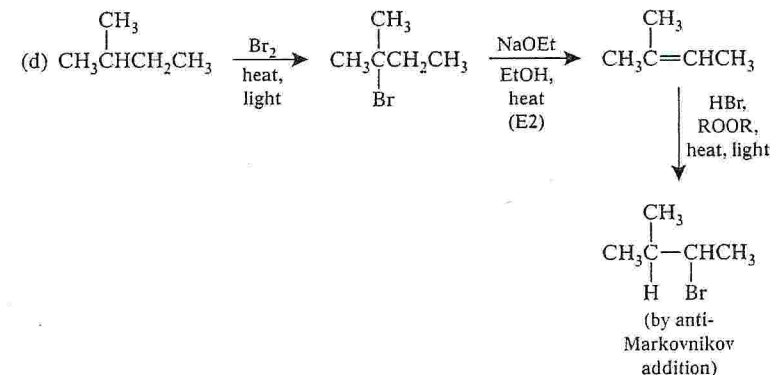
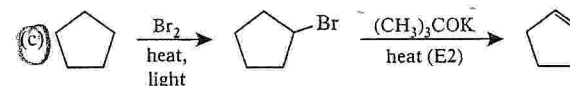
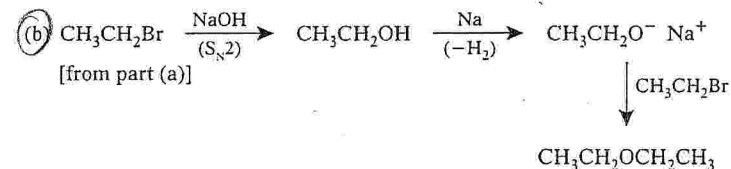
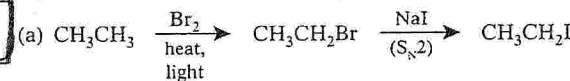
10.24 (1)  $\text{Cl}_2 \longrightarrow 2 \text{Cl}\cdot \quad \Delta H^\circ = +243 \text{ kJ mol}^{-1}$



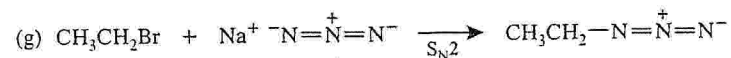
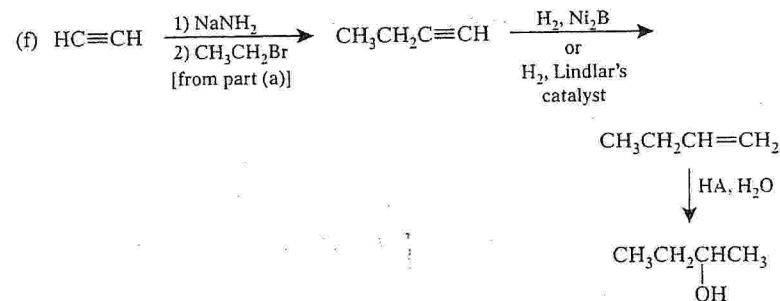
This mechanism is highly unlikely to compete with one given in Section 10.4 because step (2) of this mechanism is highly endothermic ( $\Delta H^\circ = +85.8 \text{ kJ mol}^{-1}$ ). This means that the energy of activation for this step, a chain-propagating step, will have to be larger than  $+85.8 \text{ kJ mol}^{-1}$ . Notice in Section 10.5B that neither of the chain-propagating steps for the mechanism given in Section 10.4 has an energy of activation greater than  $+15.9$

$\text{kJ mol}^{-1}$ . The alternative mechanism given in this problem, consequently, will proceed at a rate that is very much slower than the one given in Section 10.4 and will, for all practical purposes, not compete with it at all.

## 10.25

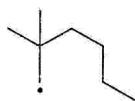




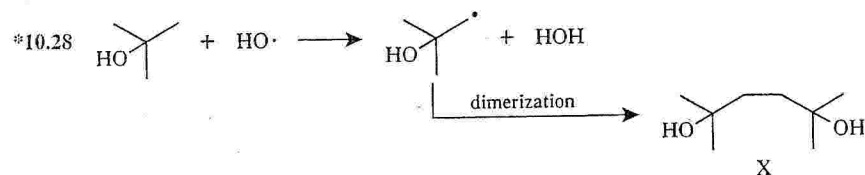


**10.26** Chlorine atoms are electronegative and abstract hydrogens according to their “electron richness.” The electronegative fluorine atom reduces electron density in proportion to its proximity to the different  $\text{CH}_2$  groups. The  $\text{CH}_3$  group is the least reactive site because the bond dissociation energy for a  $\text{CH}_3$  group is greater than that for a  $\text{CH}_2$  group.

\*10.27 Besides direct H• abstraction from C5 there would be many H• abstractions from the three methyl groups, leading to:



Any of these radicals could then, besides directly attacking chlorine, intramolecularly abstract H $\cdot$  from C5 (analogous to the "back biting" that explains branching during alkene radical polymerization).



Use the single-bond dissociation energies of Table 10.1:

Table 10.1 Single-bond homolytic dissociation energies  $DH^\circ$  at 25°C

| Compound                                                          | A : B<br>kJ mol <sup>-1</sup> | A· + B·<br>Compound                                                  | kJ mol <sup>-1</sup> |
|-------------------------------------------------------------------|-------------------------------|----------------------------------------------------------------------|----------------------|
| H-H                                                               | 435                           | (CH <sub>3</sub> ) <sub>2</sub> CH-Br                                | 285                  |
| D-D                                                               | 444                           | (CH <sub>3</sub> ) <sub>2</sub> CH-I                                 | 222                  |
| F-F                                                               | 159                           | (CH <sub>3</sub> ) <sub>2</sub> CH-OH                                | 385                  |
| Cl-Cl                                                             | 243                           | (CH <sub>3</sub> ) <sub>2</sub> CH-OCH <sub>3</sub>                  | 337                  |
| Br-Br                                                             | 192                           | (CH <sub>3</sub> ) <sub>2</sub> CHCH <sub>2</sub> -H                 | 410                  |
| I-I                                                               | 151                           | (CH <sub>3</sub> ) <sub>3</sub> C-H                                  | 381                  |
| H-F                                                               | 569                           | (CH <sub>3</sub> ) <sub>3</sub> C-Cl                                 | 328                  |
| H-Cl                                                              | 431                           | (CH <sub>3</sub> ) <sub>3</sub> C-Br                                 | 264                  |
| H-Br                                                              | 366                           | (CH <sub>3</sub> ) <sub>3</sub> C-I                                  | 207                  |
| H-I                                                               | 297                           | (CH <sub>3</sub> ) <sub>3</sub> C-OH                                 | 379                  |
| CH <sub>3</sub> -H                                                | 435                           | (CH <sub>3</sub> ) <sub>3</sub> C-OCH <sub>3</sub>                   | 326                  |
| CH <sub>3</sub> -F                                                | 452                           | C <sub>6</sub> H <sub>5</sub> CH <sub>2</sub> -H                     | 356                  |
| CH <sub>3</sub> -Cl                                               | 349                           | CH <sub>2</sub> =CHCH <sub>2</sub> -H                                | 356                  |
| CH <sub>3</sub> -Br                                               | 293                           | CH <sub>2</sub> =CH-H                                                | 452                  |
| CH <sub>3</sub> -I                                                | 234                           | C <sub>6</sub> H <sub>5</sub> -H                                     | 460                  |
| CH <sub>3</sub> -OH                                               | 383                           | HC≡C-H                                                               | 523                  |
| CH <sub>3</sub> -OCH <sub>3</sub>                                 | 335                           | CH <sub>3</sub> -CH <sub>3</sub>                                     | 368                  |
| CH <sub>3</sub> CH <sub>2</sub> -H                                | 410                           | CH <sub>3</sub> CH <sub>2</sub> -CH <sub>3</sub>                     | 356                  |
| CH <sub>3</sub> CH <sub>2</sub> -F                                | 444                           | CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -CH <sub>3</sub>     | 356                  |
| CH <sub>3</sub> CH <sub>2</sub> -Cl                               | 341                           | CH <sub>3</sub> CH <sub>2</sub> -CH <sub>2</sub> CH <sub>3</sub>     | 343                  |
| CH <sub>3</sub> CH <sub>2</sub> -Br                               | 289                           | (CH <sub>3</sub> ) <sub>2</sub> CH-CH <sub>3</sub>                   | 351                  |
| CH <sub>3</sub> CH <sub>2</sub> -I                                | 224                           | (CH <sub>3</sub> ) <sub>3</sub> C-CH <sub>3</sub>                    | 335                  |
| CH <sub>3</sub> CH <sub>2</sub> -OH                               | 383                           | HO-H                                                                 | 498                  |
| CH <sub>3</sub> CH <sub>2</sub> -OCH <sub>3</sub>                 | 335                           | HOO-H                                                                | 377                  |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -H                | 410                           | HO-OH                                                                | 213                  |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -F                | 444                           | (CH <sub>3</sub> ) <sub>3</sub> CO-OC(CH <sub>3</sub> ) <sub>3</sub> | 157                  |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -Cl               | 341                           |                                                                      |                      |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -Br               | 289                           |                                                                      |                      |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -I                | 224                           |                                                                      |                      |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -OH               | 383                           |                                                                      |                      |
| CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> -OCH <sub>3</sub> | 335                           |                                                                      |                      |
| (CH <sub>3</sub> ) <sub>2</sub> CH-H                              | 395                           |                                                                      |                      |
| (CH <sub>3</sub> ) <sub>2</sub> CH-F                              | 439                           |                                                                      |                      |
| (CH <sub>3</sub> ) <sub>2</sub> CH-Cl                             | 339                           |                                                                      |                      |



## QUIZ

- 10.1 On the basis of Table 10.1, what is the order of decreasing stability of the radicals,  $\text{HC}\equiv\text{C}\cdot$   $\text{CH}_2=\text{CH}\cdot$   $\text{CH}_2=\text{CHCH}_2\cdot$ ?

- (a)  $\text{HC}\equiv\text{C}\cdot > \text{CH}_2=\text{CH}\cdot > \text{CH}_2=\text{CHCH}_2\cdot$   
 (b)  $\text{CH}_2=\text{CH}\cdot > \text{HC}\equiv\text{C}\cdot > \text{CH}_2=\text{CHCH}_2\cdot$   
 (c)  $\text{CH}_2=\text{CHCH}_2\cdot > \text{HC}\equiv\text{C}\cdot > \text{CH}_2=\text{CH}\cdot$   
 (d)  $\text{CH}_2=\text{CHCH}_2\cdot > \text{CH}_2=\text{CH}\cdot > \text{HC}\equiv\text{C}\cdot$   
 (e)  $\text{CH}_2=\text{CH}\cdot > \text{CH}_2=\text{CHCH}_2\cdot > \text{HC}\equiv\text{C}\cdot$

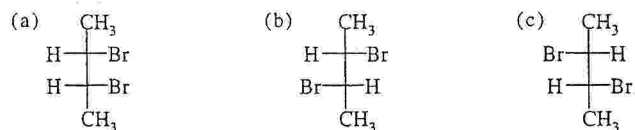
- 10.2 In the radical chlorination of methane, one propagation step is shown as  
 $\text{Cl}\cdot + \text{CH}_4 \longrightarrow \text{HCl} + \cdot\text{CH}_3$

Why do we eliminate the possibility that this step goes as shown below?



- (a) Because in the next propagation step,  $\text{H}\cdot$  would have to react with  $\text{Cl}_2$  to form  $\text{Cl}\cdot$  and  $\text{HCl}$ ; this reaction is not feasible.  
 (b) Because this alternative step has a more endothermic  $\Delta H^\circ$  than the first.  
 (c) Because free hydrogen atoms cannot exist.  
 (d) Because this alternative step is not consistent with the high photochemical efficiency of this reaction.

- 10.3 Pure (*S*)- $\text{CH}_3\text{CH}_2\text{CHBrCH}_3$  is subjected to monobromination to form several isomers of  $\text{C}_4\text{H}_8\text{Br}_2$ . Which of the following is not produced?



- (d)  $\text{CH}_3\text{CH}_2\text{CBr}_2\text{CH}_3$  (e) (*R*)- $\text{CH}_3\text{CH}_2\text{CHBrCH}_2\text{Br}$

- 10.4 Using the data of Table 10.1, calculate the heat of reaction,  $\Delta H^\circ$ , of the reaction,

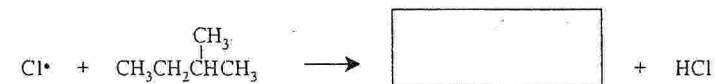


- (a)  $52.3 \text{ kJ mol}^{-1}$  (b)  $-52.3 \text{ kJ mol}^{-1}$  (c)  $1257 \text{ kJ mol}^{-1}$   
 (d)  $-1257 \text{ kJ mol}^{-1}$  (e)  $-244.8 \text{ kJ mol}^{-1}$

- 10.5 Which gas-phase reaction would have  $E_{\text{act}} = 0$ ?

- (a)  $\text{CH}_3\cdot + (\text{CH}_3)_3\text{C}-\text{H} \longrightarrow \text{CH}_4 + (\text{CH}_3)_3\text{C}\cdot$   
 (b)  $\text{CH}_3\cdot + \text{CH}_3\text{CH}_3 \longrightarrow \text{CH}_4 + \text{CH}_3\text{CH}_2\cdot$   
 (c)  $\text{CH}_3\text{CH}_2\cdot + \text{CH}_3\text{CH}_2\cdot \longrightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$   
 (d)  $\text{Br}\cdot + \text{H}-\text{Cl} \longrightarrow \text{H}-\text{Br} + \text{Cl}\cdot$   
 (e)  $\text{Br}\cdot + \text{H}-\text{I} \longrightarrow \text{H}-\text{Br} + \text{I}\cdot$

- 10.6 What is the most stable radical that would be formed in the following reaction?



- 10.7 The reaction of 2-methylbutane with chlorine would yield a total of \_\_\_\_\_ different monochloro products (including stereoisomers).

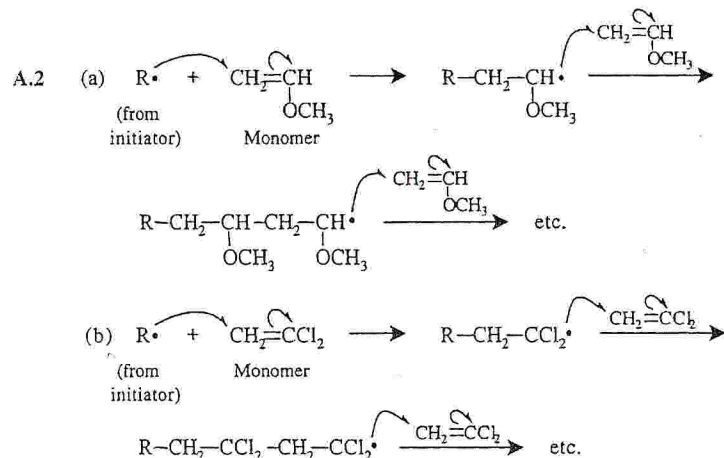
- 10.8 For which reaction would the transition state most resemble the products?

- (a)  $\text{CH}_4 + \text{F}\cdot \longrightarrow \text{CH}_3\cdot + \text{HF}$   
 (b)  $\text{CH}_4 + \text{Cl}\cdot \longrightarrow \text{CH}_3\cdot + \text{HCl}$   
 (c)  $\text{CH}_4 + \text{Br}\cdot \longrightarrow \text{CH}_3\cdot + \text{HBr}$   
 (d)  $\text{CH}_4 + \text{I}\cdot \longrightarrow \text{CH}_3\cdot + \text{HI}$

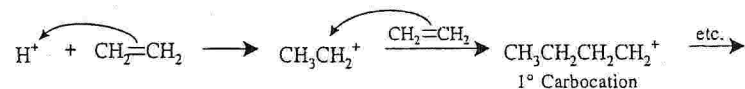
# A SPECIAL TOPIC

## Chain-Growth Polymers

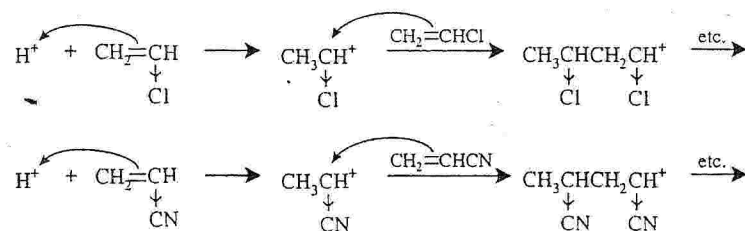
A.1 Head-to-tail polymerization leads to a more stable radical on the growing polymer chain. In head-to-tail coupling, the radical is 2° (actually 2° benzylic, and as we shall see in Section 15.12A this makes it even more stable). In head-to-head coupling, the radical is 1°.



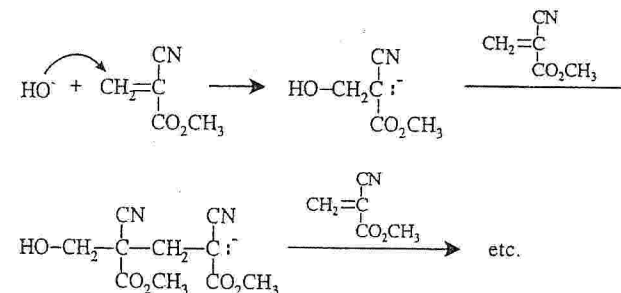
A.3 In the cationic polymerization of isobutylene (see text), the growing polymer chain has a stable 3° carbocation at the end. In the cationic polymerization of ethene, for example, the intermediates would be much less stable 1° cations.



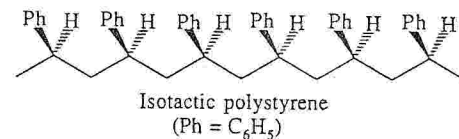
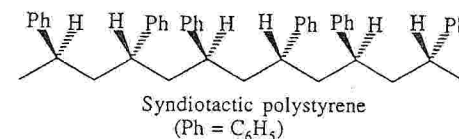
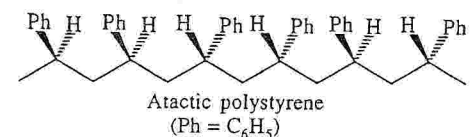
With vinyl chloride and acrylonitrile, the cations at the end of the growing chain would be destabilized by electron-withdrawing groups.



A.4



A.5 (a)

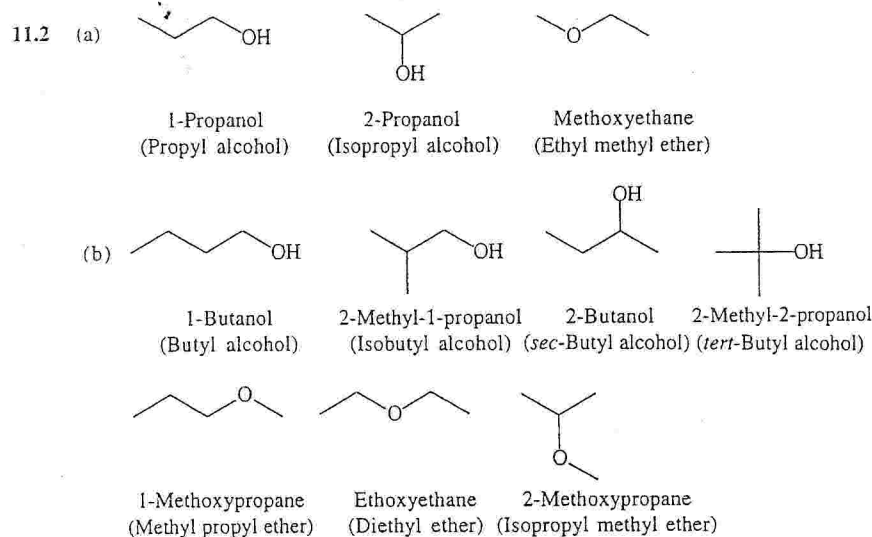


(b) The solution of isotactic polystyrene.

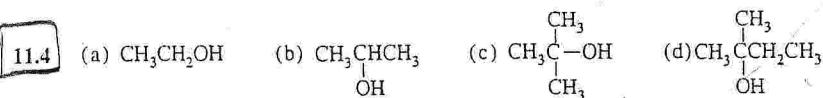
## ALCOHOLS AND ETHERS

## SOLUTIONS TO PROBLEMS

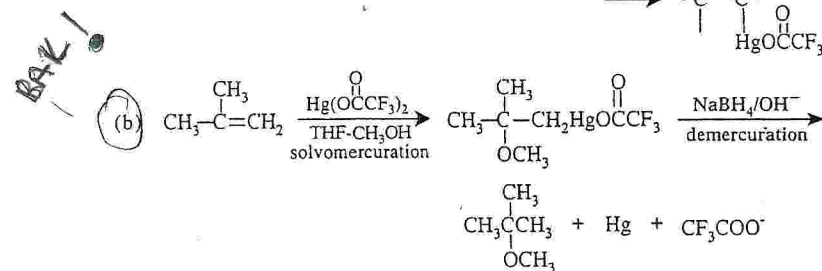
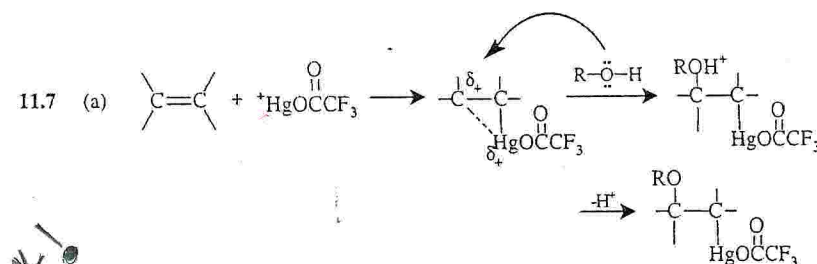
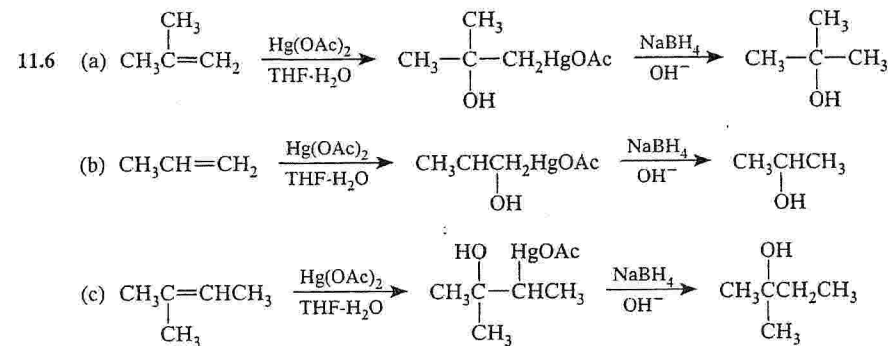
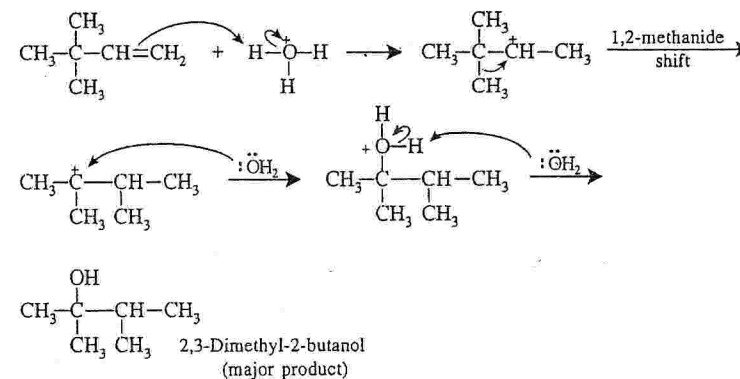
11.1 These names mix two systems of nomenclature (radicofunctional and substitutive; see Section 4.3F). The proper names are: isopropyl alcohol (radicofunctional) or 2-propanol (substitutive), and *tert*-butyl alcohol (radicofunctional) and 2-methyl-2-propanol (substitutive). Names with mixed systems of nomenclature should not be used.

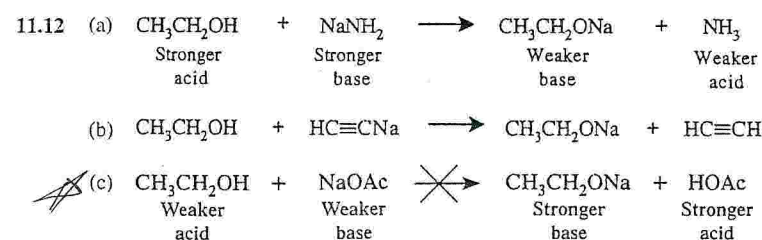
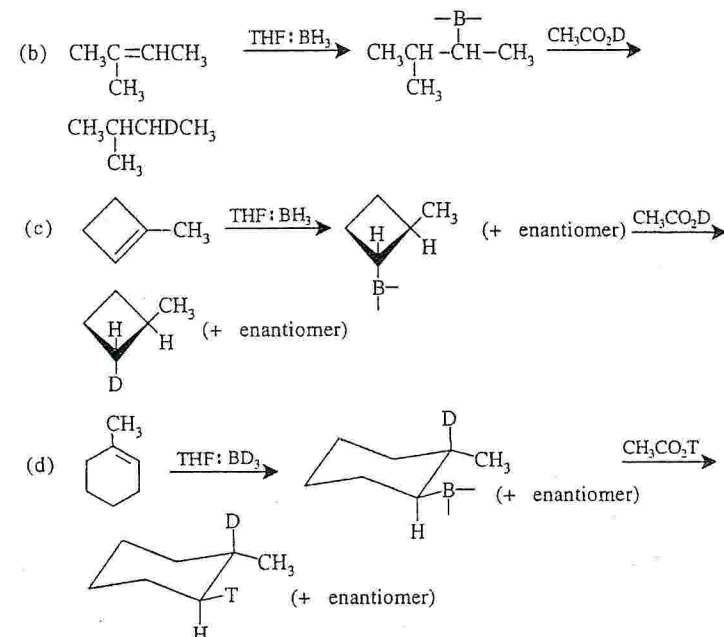
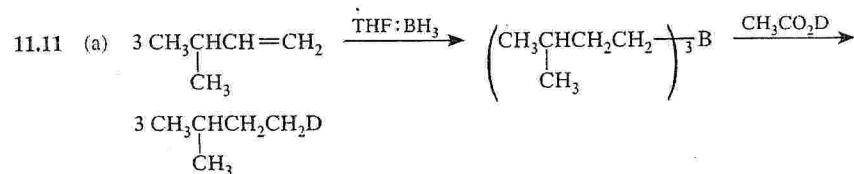
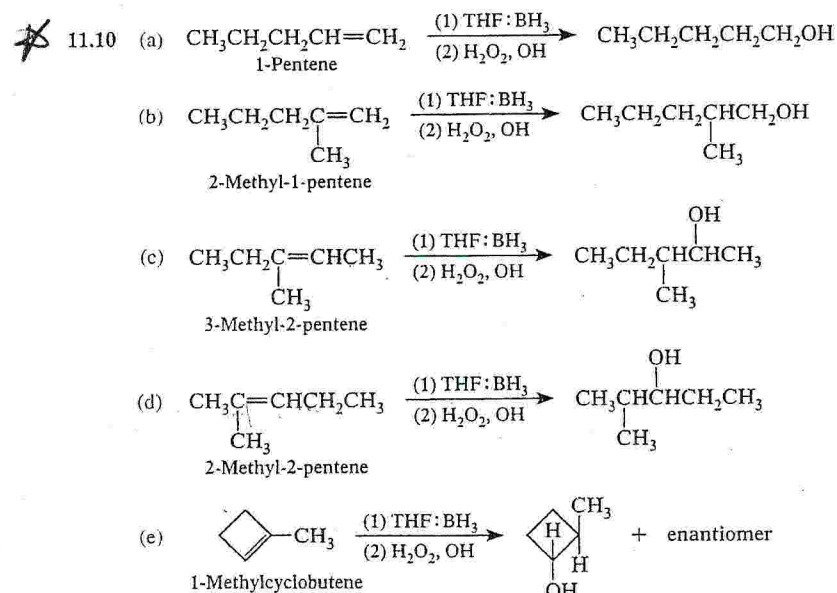
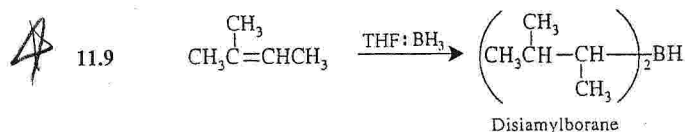
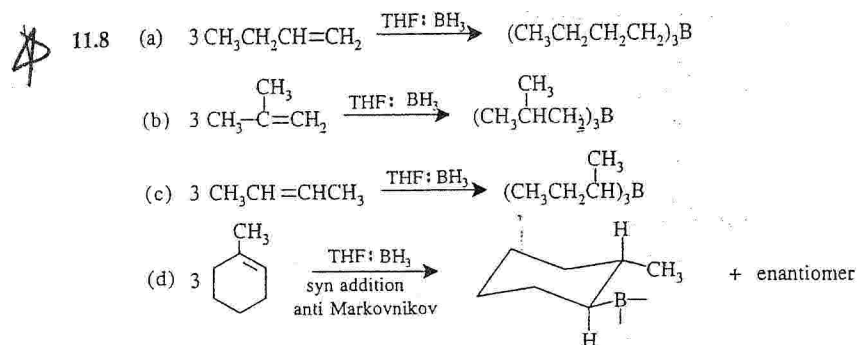


11.3 The presence of two  $-OH$  groups in each molecule of 1,2-propanediol and 1,3-propanediol allows their molecules to form more hydrogen bonds. Greater hydrogen-bond formation means that the molecules of 1,2-propanediol and 1,3-propanediol are more highly associated, and, consequently, their boiling points are higher.

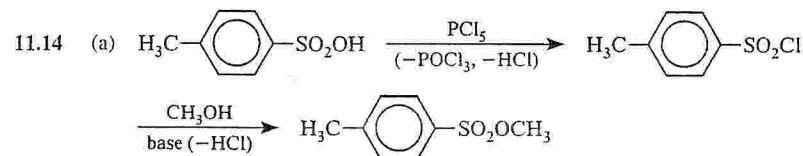
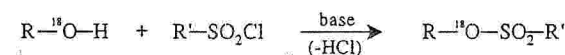


11.5 A rearrangement takes place.

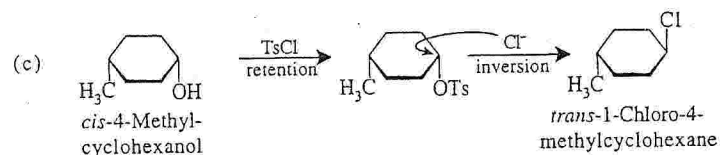
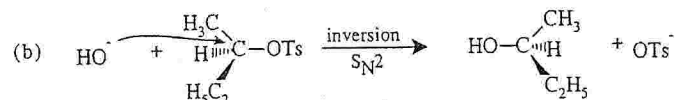
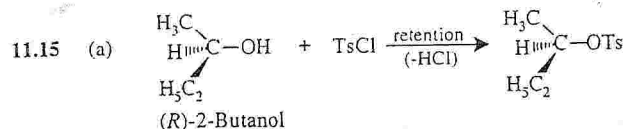
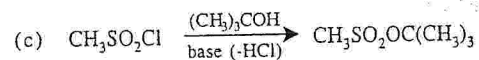
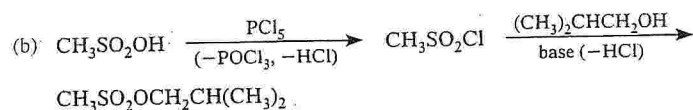




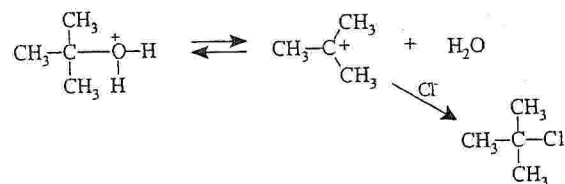
11.13 Use an alcohol containing labeled oxygen. If all of the label appears in the sulfonate ester, then one can conclude that the alcohol C-O bond does not break during the reaction:





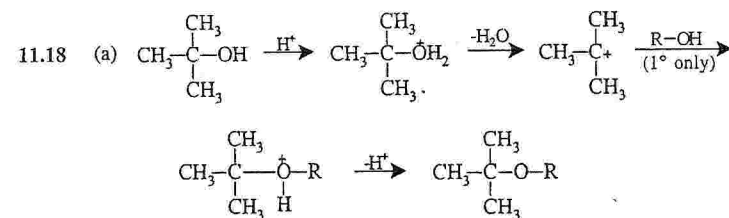
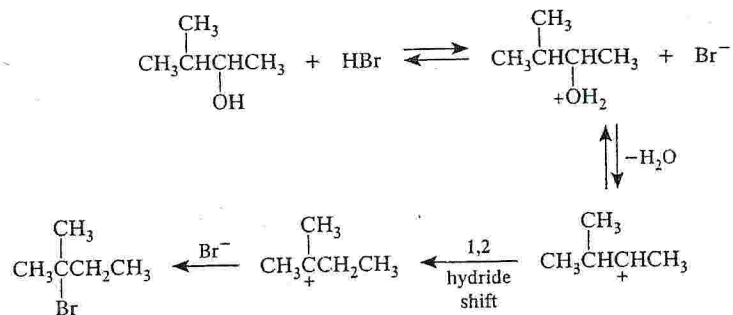


- 11.16 (a) Tertiary alcohols react faster than secondary alcohols because they form more stable carbocations; that is, 3° rather than 2°:

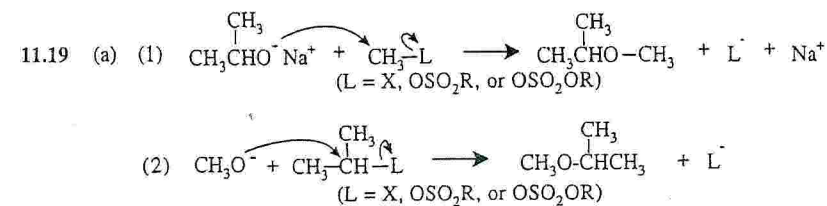


- (b)  $\text{CH}_3\text{OH}$  reacts faster than 1° alcohols because it offers less hindrance to  $\text{S}_\text{N}2$  attack. (Recall that  $\text{CH}_3\text{OH}$  and 1° alcohols must react through an  $\text{S}_\text{N}2$  mechanism.)

11.17



This reaction succeeds because a 3° carbocation is much more stable than a 1° carbocation. Consequently, mixing the 1° alcohol and  $\text{H}_2\text{SO}_4$  does not lead to formation of appreciable amounts of a 1° carbocation. However, when the 3° alcohol is added, it is rapidly converted to a 3° carbocation, which then reacts with the 1° alcohol that is present in the mixture.

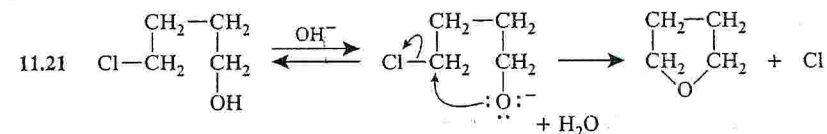


- (b) Both methods involve  $\text{S}_\text{N}2$  reactions. Therefore, method (1) is better because substitution takes place at an unhindered methyl carbon atom. In method (2) where substitution must take place at a relatively hindered secondary carbon atom, the reaction would be accompanied by considerable elimination.

- 11.20 Reaction of the alcohol with K and then of the resulting salt with  $\text{C}_2\text{H}_5\text{Br}$  does not break bonds to the stereocenter, and these reactions therefore occur with retention of configuration at the stereocenter.

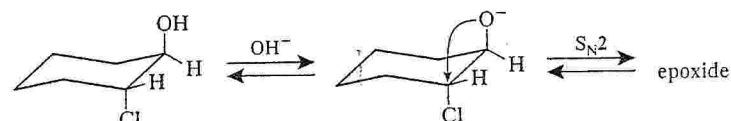
Reaction of the tosylate,  $\text{C}_6\text{H}_5\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$ , with  $\text{C}_2\text{H}_5\text{OH}$  in  $\text{K}_2\text{CO}_3$  solution, however,

is an  $\text{S}_\text{N}2$  reaction that takes place at the stereocenter and thus it occurs with inversion at the stereocenter.



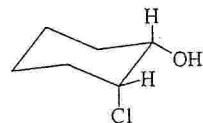


(b) The  $\text{O}^-$  group must displace the  $\text{Cl}^-$  from the backside,

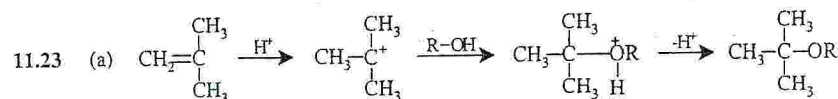


*trans*-2-Chlorocyclohexanol

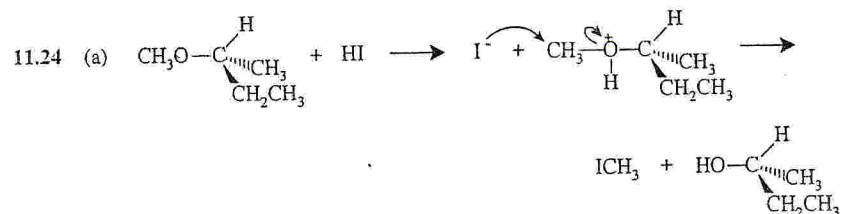
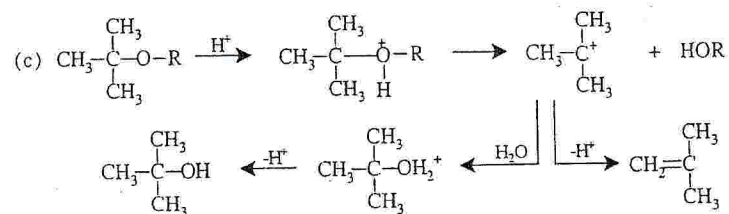
Backside attack is not possible with the *cis* isomer (below); therefore, it does not form an epoxide.



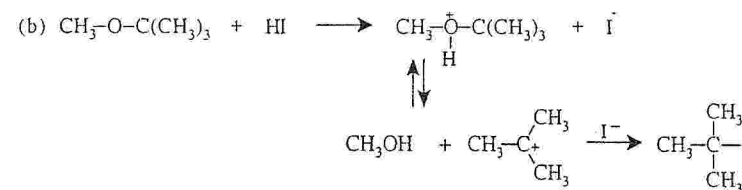
*cis*-2-Chlorocyclohexanol



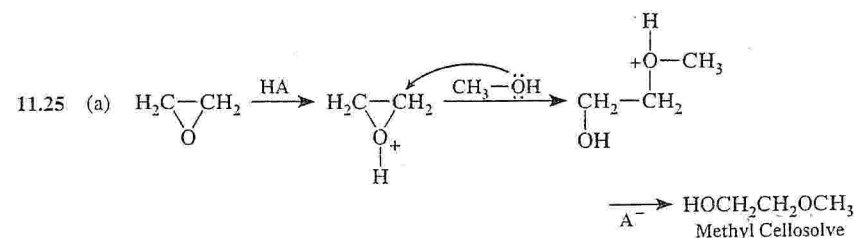
(b) The *tert*-butyl group is easily removed because, in acid, it is easily converted to a relatively stable, tertiary carbocation.



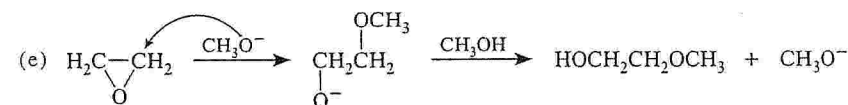
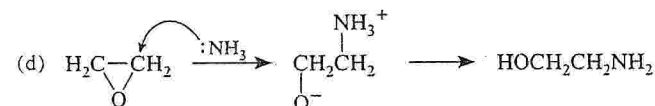
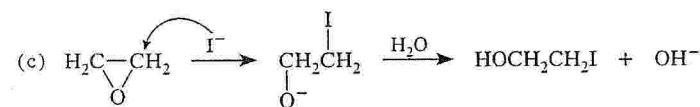
$\text{S}_{\text{N}}2$  attack of  $\text{I}^-$  occurs at the methyl carbon atom because it is less hindered; therefore, the bond between the *sec*-butyl group and the oxygen is not broken.



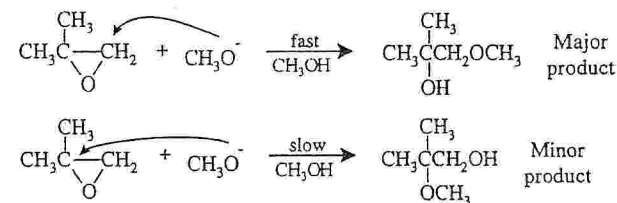
In this reaction the much more stable *tert*-butyl cation is produced. It then combines with  $\text{I}^-$  to form *tert*-butyl iodide.



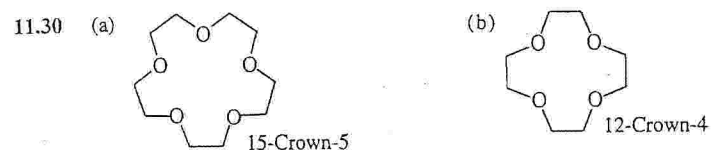
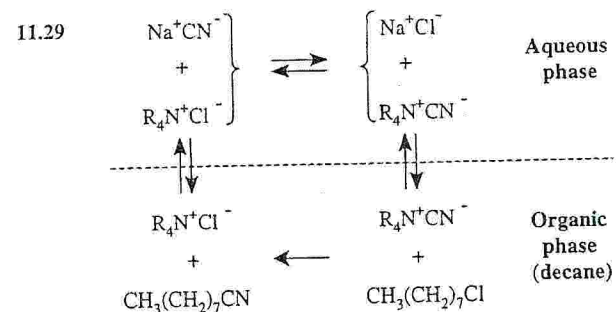
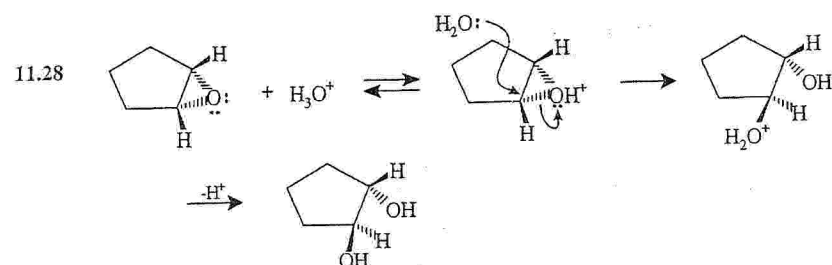
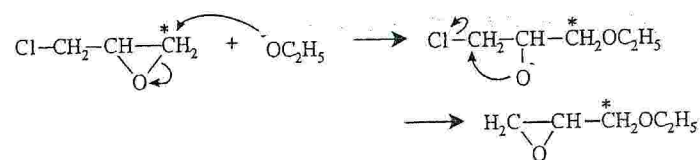
(b) An analogous reaction yields ethyl cellosolve,  $\text{HOCH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$ .



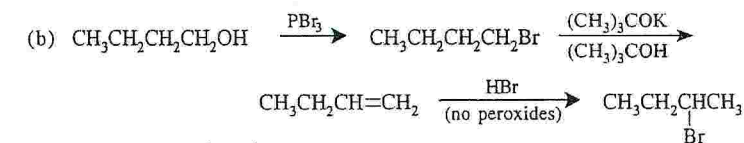
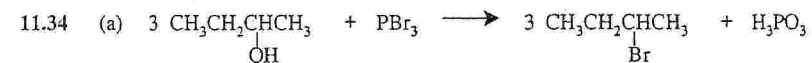
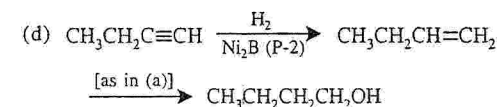
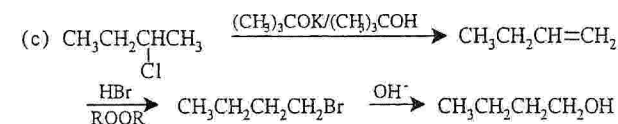
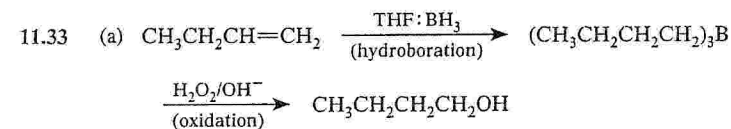
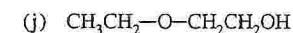
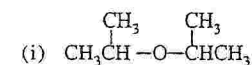
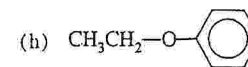
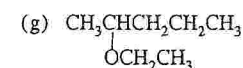
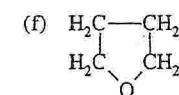
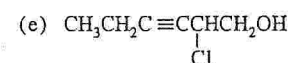
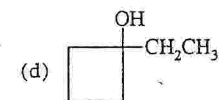
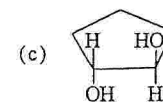
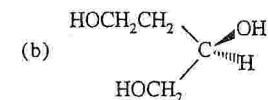
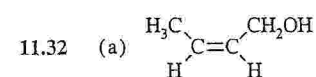
11.26 The reaction is an  $\text{S}_{\text{N}}2$  reaction, and thus nucleophilic attack takes place much more rapidly at the primary carbon atom than at the more hindered secondary carbon atom.



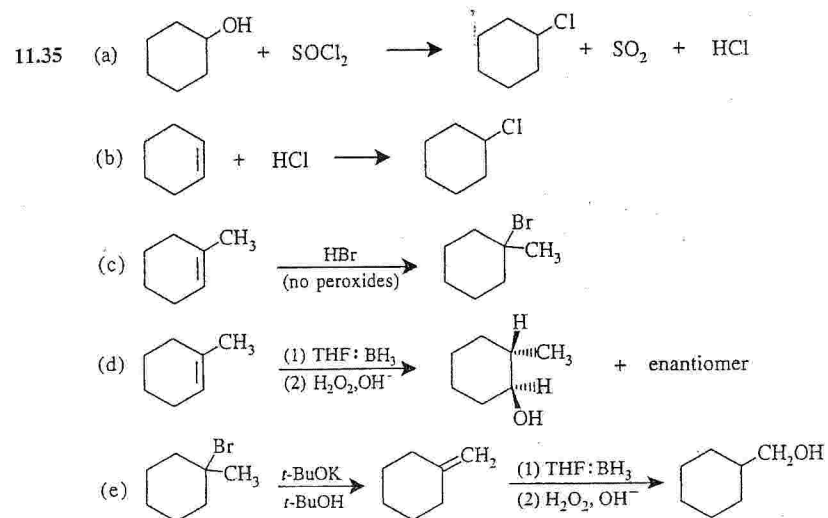
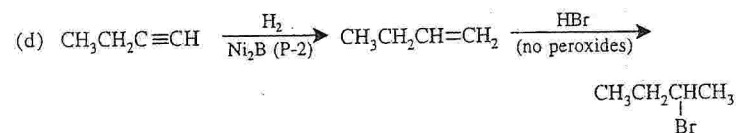
- 11.27 Ethoxide ion attacks the epoxide ring at the primary carbon because it is less hindered, and the following reactions take place.



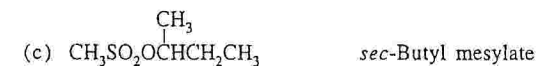
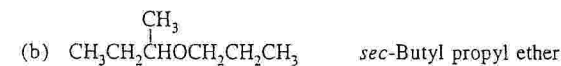
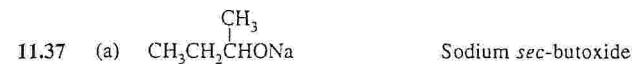
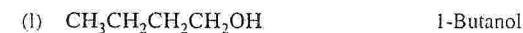
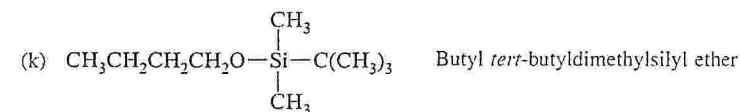
- 11.31 (a) 3,3-Dimethyl-1-butanol  
(b) 4-Penten-2-ol  
(c) 2-Methyl-1,4-butanediol  
(d) 2-Phenylethanol  
(e) 1-Methyl-2-cyclopenten-1-ol  
(f) *cis*-3-Methylcyclohexanol



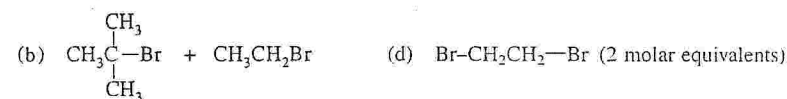
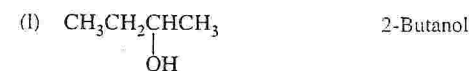
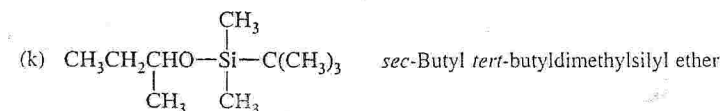
(c) See (b) above.



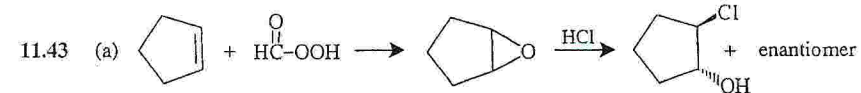
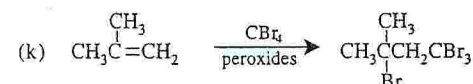
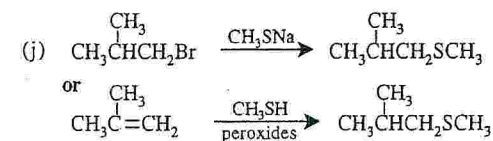
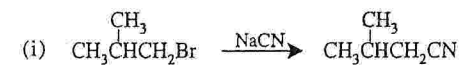
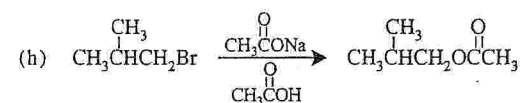
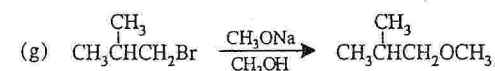
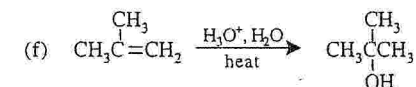
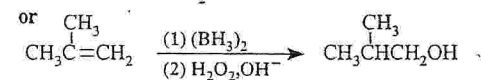
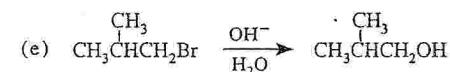
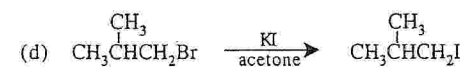
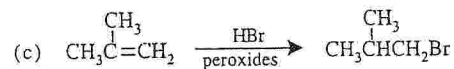
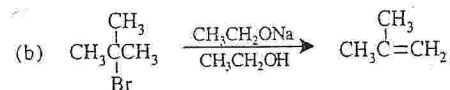
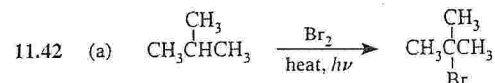
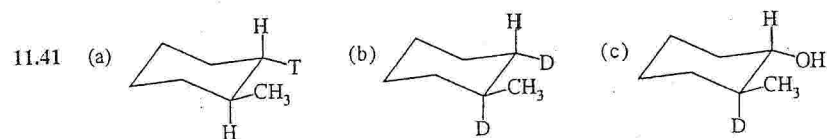
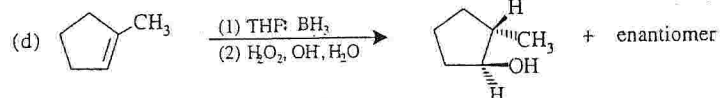
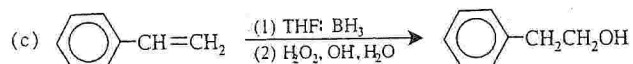
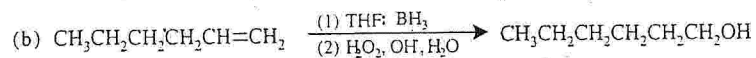
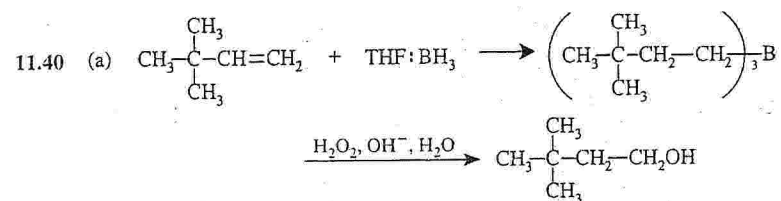
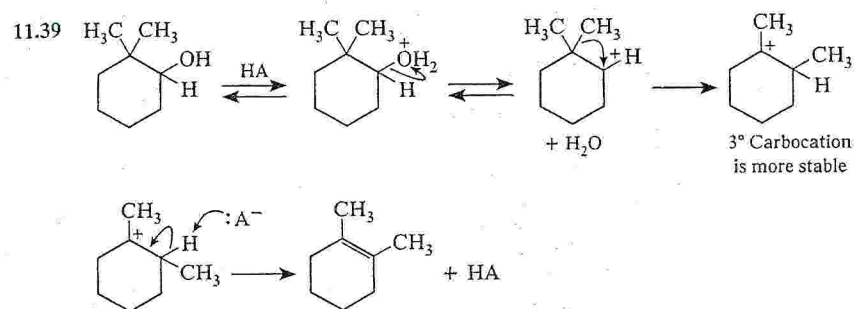
- 11.36 (a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{ONa}$  Sodium butoxide  
 (b)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_3$  Butyl propyl ether  
 (c)  $\text{CH}_3\text{SO}_2\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$  Butyl mesylate  
 (d)  $\text{H}_3\text{C}-\text{C}_6\text{H}_4-\text{SO}_2\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$  Butyl tosylate  
 (e)  $\text{CH}_3\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$  1-Methoxybutane  
 (f)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{I}$  Butyl iodide  
 (g)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}$  Butyl chloride  
 (h) same as (g)  
 (i)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$  Dibutyl ether  
 (j)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$  Butyl bromide



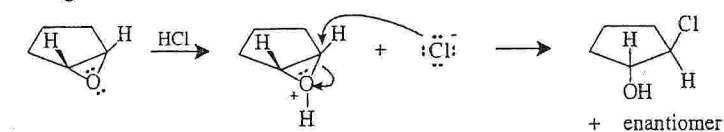
(h) same as (g)

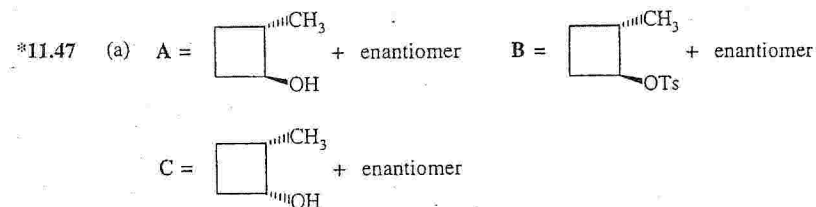
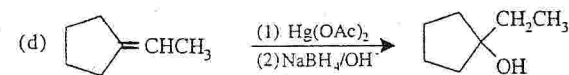
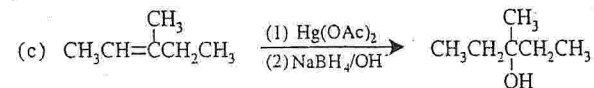
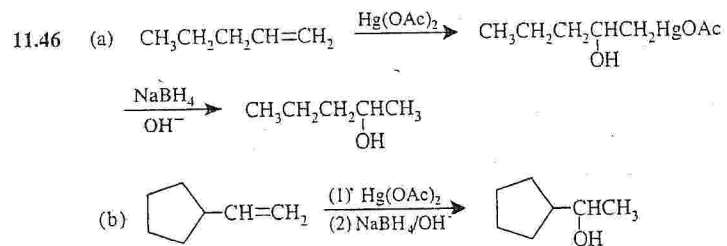
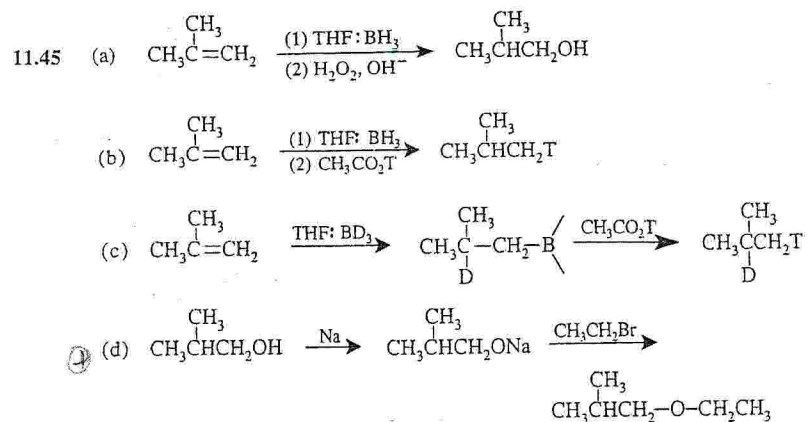
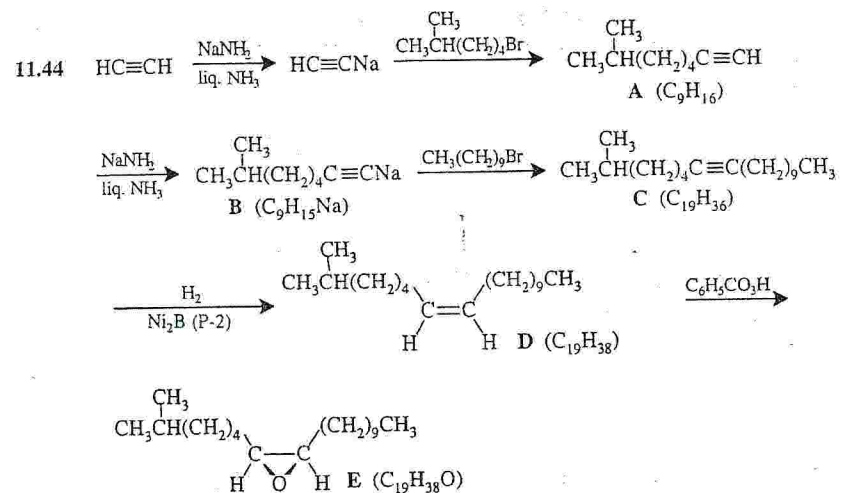




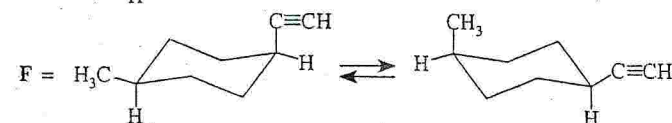
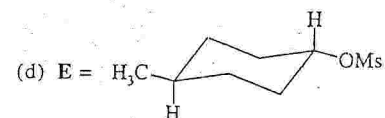
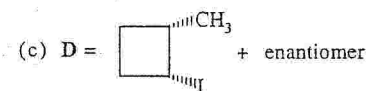


(b) The trans product because the  $\text{Cl}^-$  attacks anti to the epoxide and an inversion of configuration occurs.



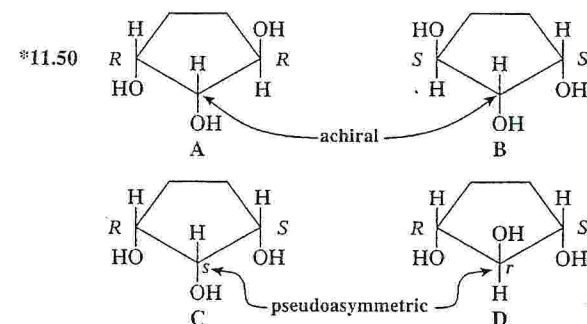
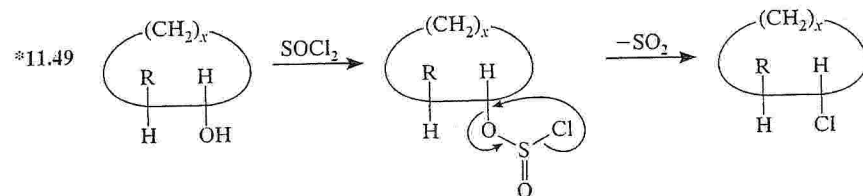
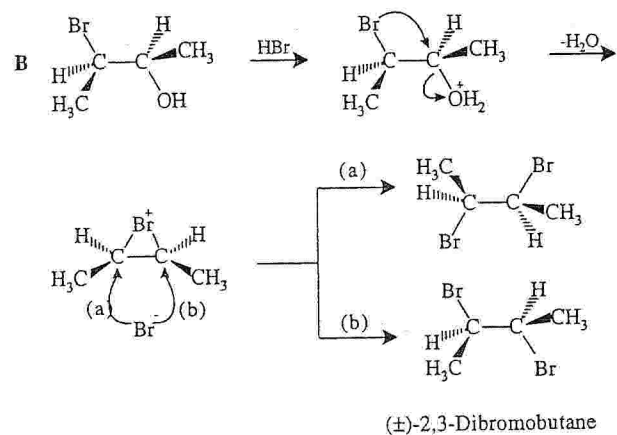
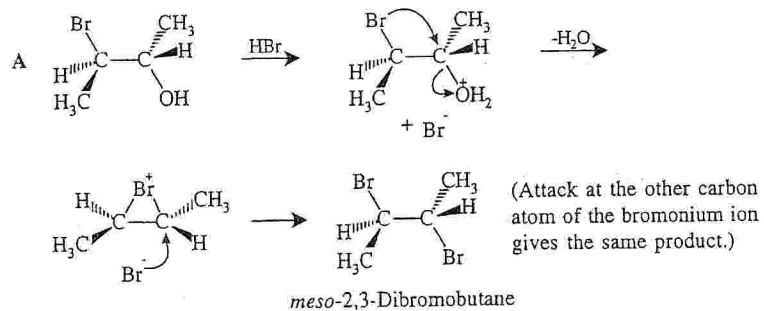


(b) Diastereomers



(g) Enantiomers

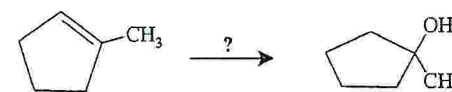
\*11.48 The reactions proceed through the formation of bromonium ions identical to those formed in the bromination of *trans*- and *cis*-2-butene (see Section 8.7A).



A and B are enantiomers  
A, C, and D are all diastereomers  
B, C, and D are all diastereomers  
C is meso  
D is meso

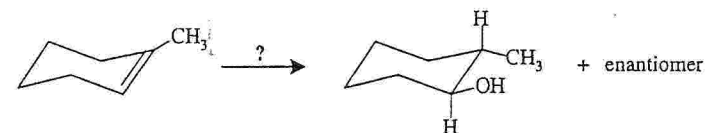
## QUIZ

11.1 Which set of reagents would effect the conversion,



- (a)  $\text{BH}_3$ , THF, then  $\text{H}_2\text{O}_2/\text{OH}^-$  (b)  $\text{H}_2\text{O}/\text{Hg}(\text{OAc})_2$ , THF, then  $\text{NaBH}_4/\text{OH}^-$   
(c)  $\text{H}_3\text{O}^+$ ,  $\text{H}_2\text{O}$ , heat (d) More than one of these (e) None of these

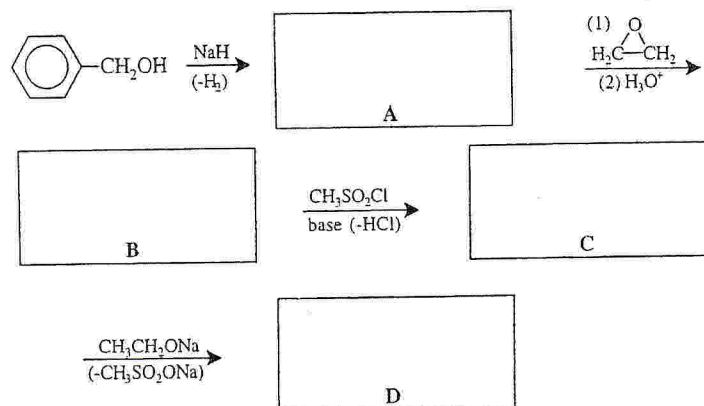
11.2 Which of the reagents in item 11.1 would effect the conversion,



11.3 The following compounds have identical molecular weights. Which would have the lowest boiling point?

- (a) 1-Butanol
- (b) 2-Butanol
- (c) 2-Methyl-1-propanol
- (d) 1,1-Dimethylethanol
- (e) 1-Methoxypropane

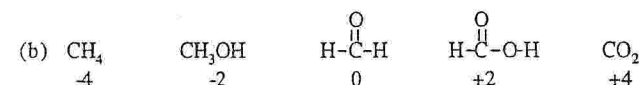
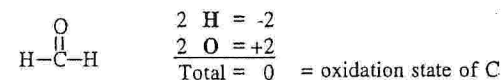
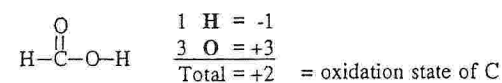
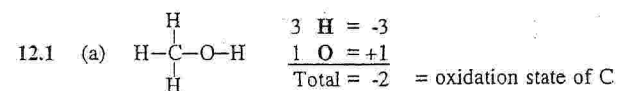
11.4 Complete the following synthesis:



# 12

## ALCOHOLS FROM CARBONYL COMPOUNDS: OXIDATION-REDUCTION AND ORGANOMETALLIC COMPOUNDS

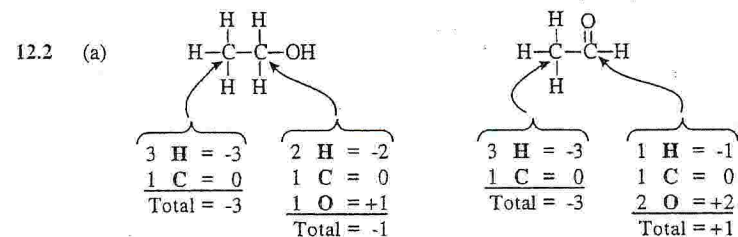
### SOLUTIONS TO PROBLEMS



(c) A change from -2 to 0

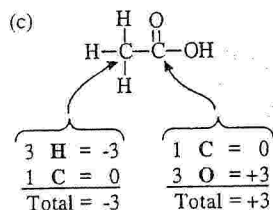
(d) An oxidation, since the oxidation state increases

(e) A reduction from +6 to +3



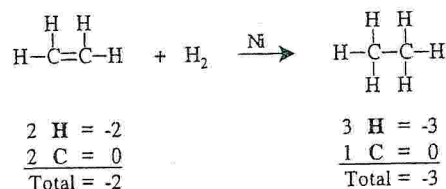


(b) Only the carbon atom of the  $-\text{CH}_2\text{OH}$  group of ethanol undergoes a change in oxidation state. The oxidation state of the carbon atom in the  $\text{CH}_3-$  group remains unchanged.



The oxygen-bearing carbon atom increases its oxidation state from +1 (in acetaldehyde) to +3 (in acetic acid).

- 12.3 (a) If we consider the hydrogenation of ethene as an example, we find that the oxidation state of carbon decreases. Thus, because the reaction involves the *addition* of hydrogen, it is both an *addition reaction* and a *reduction*.



(b) The hydrogenation of acetaldehyde is not only an addition reaction, but it is also a *reduction* because the carbon atom of the  $\text{C}=\text{O}$  group goes from a +1 to a -1 oxidation state. The reverse reaction (the *dehydrogenation* of ethanol) is not only an *elimination* reaction, but also an *oxidation*.

## Ion-Electron Half-Reaction Method for Balancing Organic Oxidation-Reduction Equations

Only two simple rules are needed:

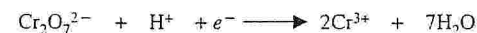
**Rule 1** Electrons ( $e^-$ ) together with protons ( $\text{H}^+$ ) are arbitrarily considered the reducing agents in the half-reaction for the reduction of the oxidizing agent. Ion charges are balanced by *adding electrons to the left-hand side*. (If the reaction is run in neutral or basic solution, add an equal number of  $\text{OH}^-$  ions to both sides of the balanced half-reaction to neutralize the  $\text{H}^+$ , and show the resulting  $\text{H}^+ + \text{OH}^-$  as  $\text{H}_2\text{O}$ .)

**Rule 2** Water ( $\text{H}_2\text{O}$ ) is arbitrarily taken as the formal source of oxygen for the oxidation of the organic compound, producing *product*, *protons*, and *electrons* on the right-hand side. (Again, use  $\text{OH}^-$  to neutralize  $\text{H}^+$  in the *balanced* half-reaction in neutral or basic media.)

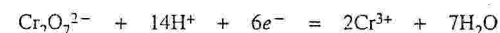
### EXAMPLE 1

Write a balanced equation for the oxidation of  $\text{RCH}_2\text{OH}$  to  $\text{RCO}_2\text{H}$  by  $\text{Cr}_2\text{O}_7^{2-}$  in acid solution.

Reduction half-reaction:



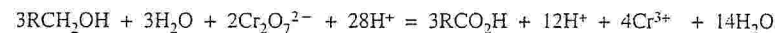
Balancing atoms and charges:



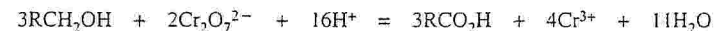
Oxidation half-reaction:



The least common multiple of a 6-electron uptake in the reduction step and a 4-electron loss in the oxidation step is 12, so we multiply the first half-reaction by 2 and the second by 3, and add:



Canceling common terms, we get:

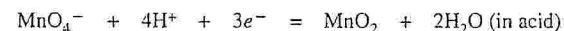


This shows that the oxidation of 3 mol of a primary alcohol to a carboxylic acid requires 2 mol of dichromate.

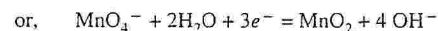
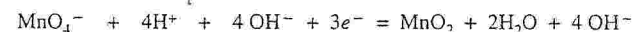
### EXAMPLE 2

Write a balanced equation for the oxidation of styrene to benzoate ion and carbonate ion by  $\text{MnO}_4^-$  in alkaline solution.

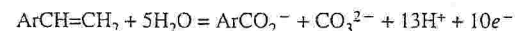
Reduction:



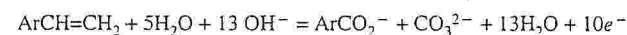
Since this reaction is carried out in basic solution, we must add 4  $\text{OH}^-$  to neutralize the 4  $\text{H}^+$  on the left side, and, of course, 4  $\text{OH}^-$  to the right side to maintain a balanced equation.



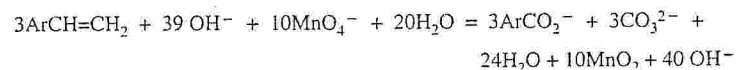
Oxidation:



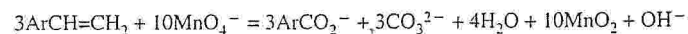
We add 13  $\text{OH}^-$  to each side to neutralize the  $\text{H}^+$  on the right side,



The least common multiple is 30, so we multiply the reduction half-reaction by 10 and the oxidation half-reaction by 3 and add:



Canceling:



## SAMPLE PROBLEMS

Using the ion-electron half-reaction method, write balanced equations for the following oxidation reactions.

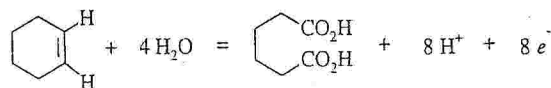
- (a) Cyclohexene +  $\text{MnO}_4^- + \text{H}^+$   $\xrightarrow{\text{hot}}$   $\text{HO}_2\text{C}(\text{CH}_2)_4\text{CO}_2\text{H} + \text{Mn}^{2+} + \text{H}_2\text{O}$   
 (b) Cyclopentene +  $\text{MnO}_4^- + \text{H}_2\text{O}$   $\xrightarrow{\text{cold}}$  *cis*-1,2-cyclopentanediol +  $\text{MnO}_2 + \text{OH}^-$   
 (c) Cyclopentanol +  $\text{HNO}_3$   $\xrightarrow{\text{hot}}$   $\text{HO}_2\text{C}(\text{CH}_2)_3\text{CO}_2\text{H} + \text{NO}_2 + \text{H}_2\text{O}$   
 (d) 1,2,3-Cyclohexanetriol +  $\text{HIO}_4$   $\xrightarrow{\text{cold}}$   $\text{OCH}(\text{CH}_2)_3\text{CHO} + \text{HCO}_2\text{H} + \text{HIO}_3$

## SOLUTIONS TO SAMPLE PROBLEMS

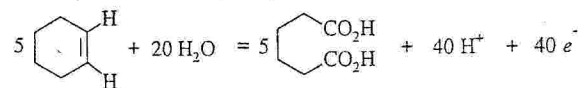
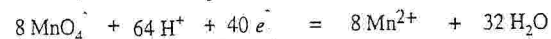
(a) Reduction:



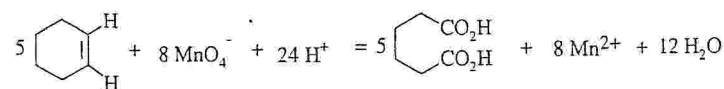
Oxidation:



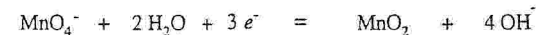
The least common multiple is 40:



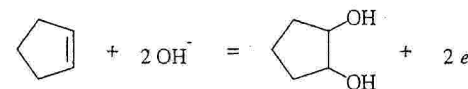
Adding and canceling:



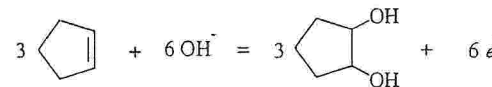
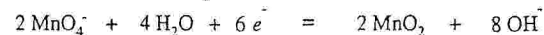
(b) Reduction:



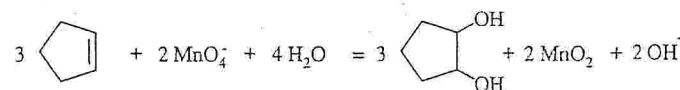
Oxidation:



The least common multiple is 6:



Adding and cancelling:



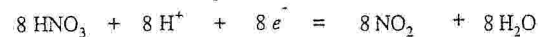
(c) Reduction:



Oxidation:



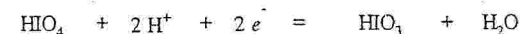
The least common multiple is 8:



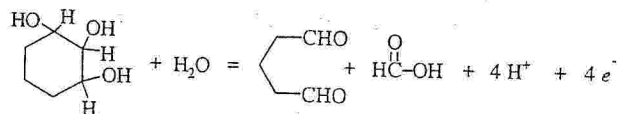
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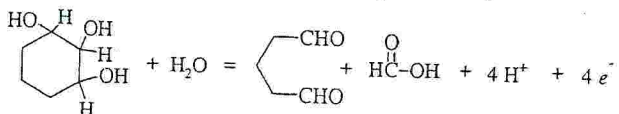
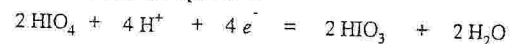
(d) Reduction:



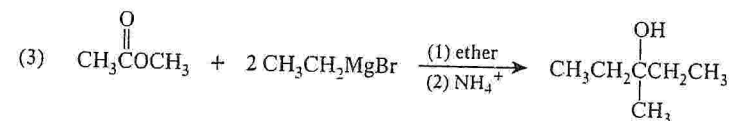
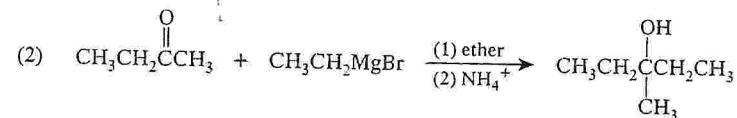
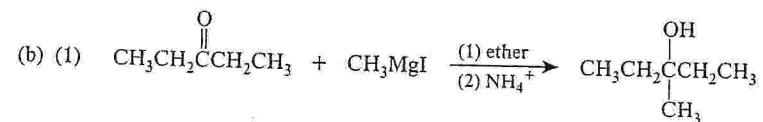
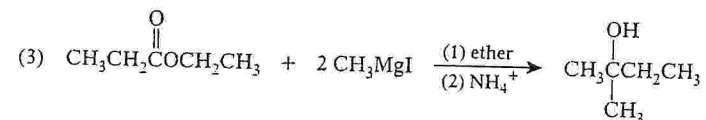
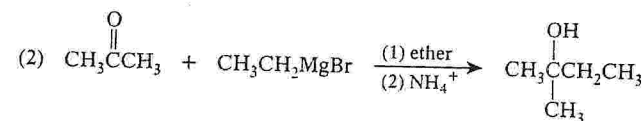
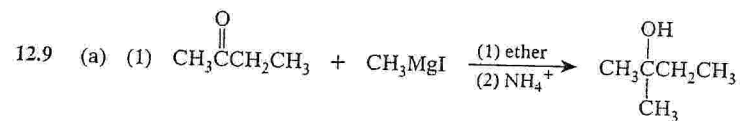
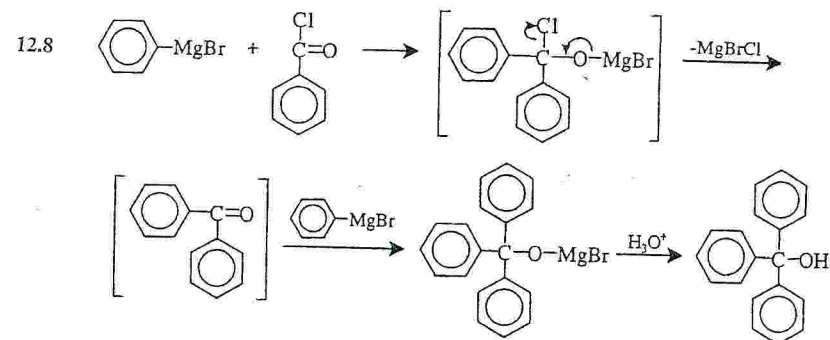
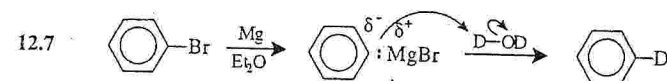
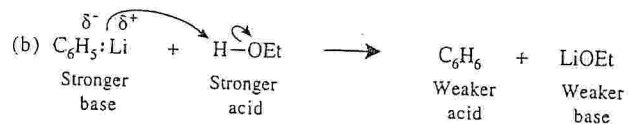
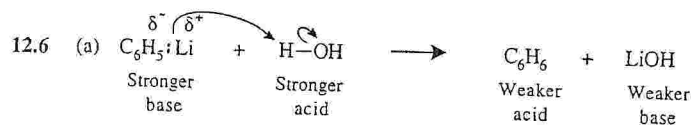
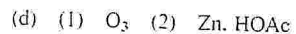
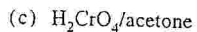
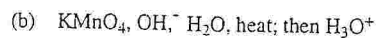
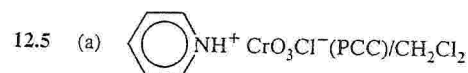
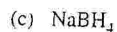
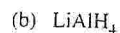
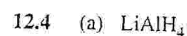
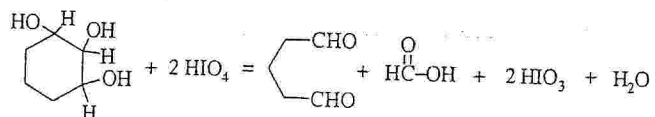
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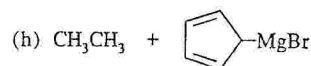
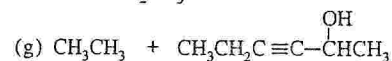
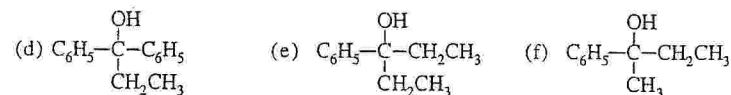
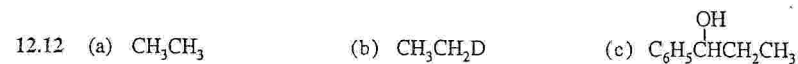
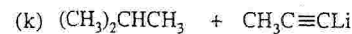
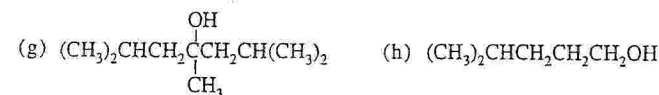
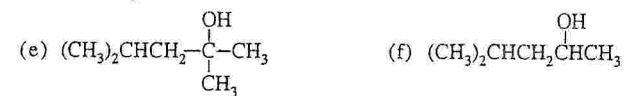
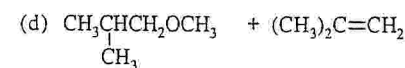
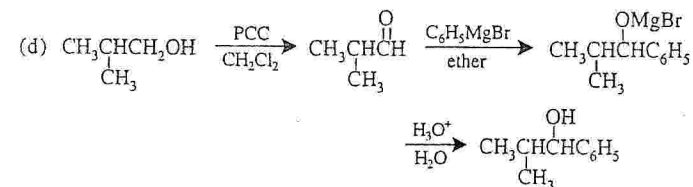
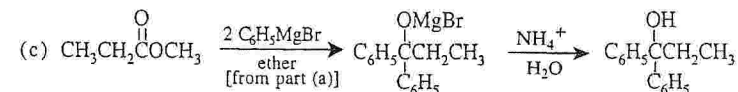
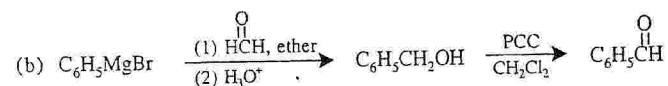
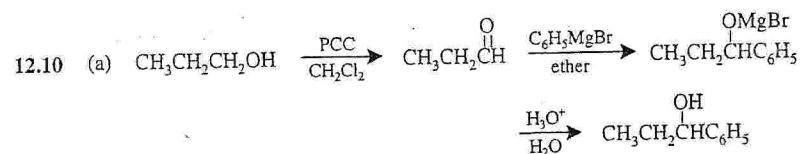
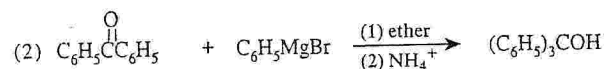
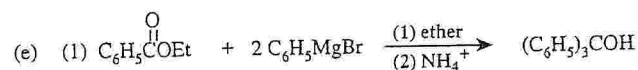
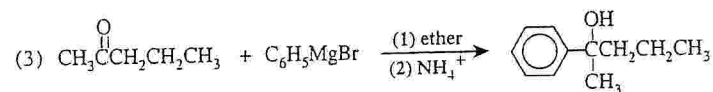
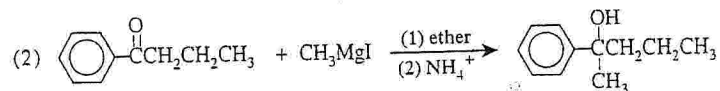
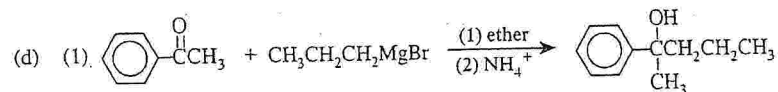
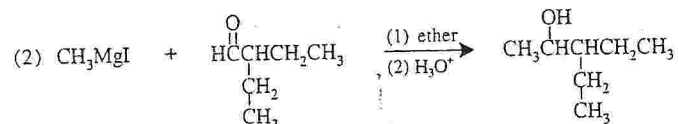
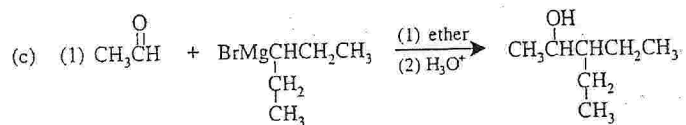


The least common multiple is 4:

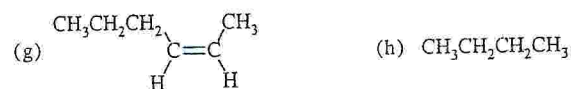
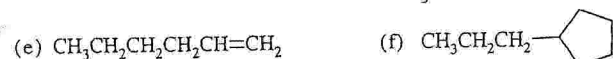
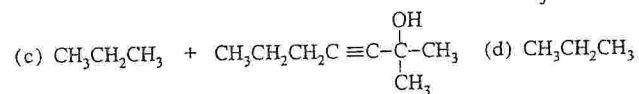
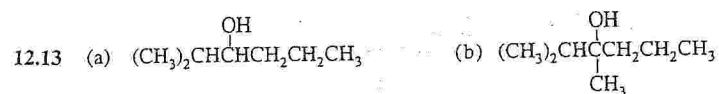


Adding and cancelling:

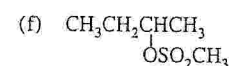
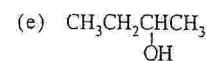
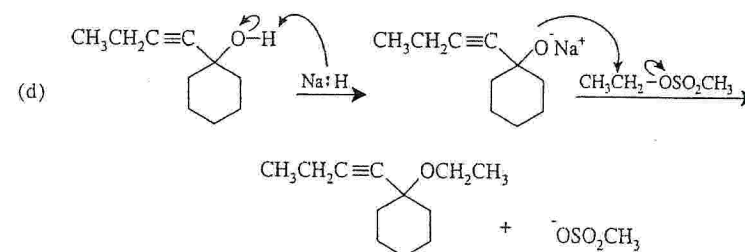
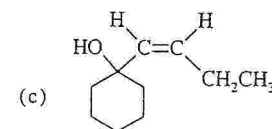
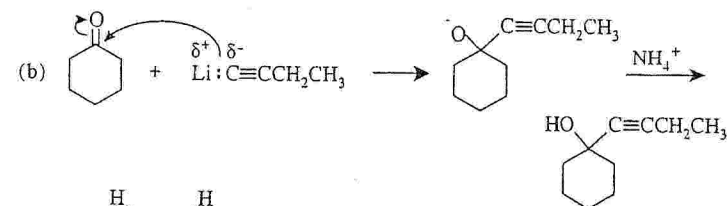
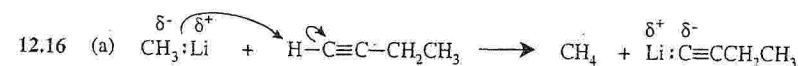
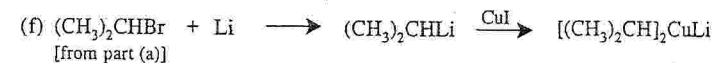
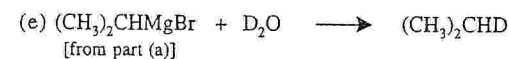
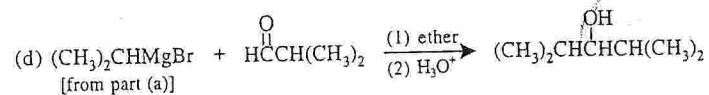
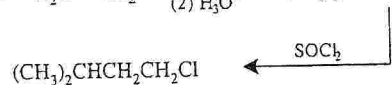
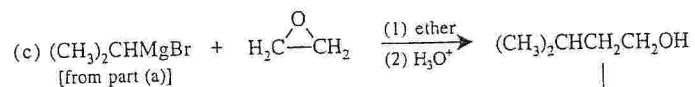
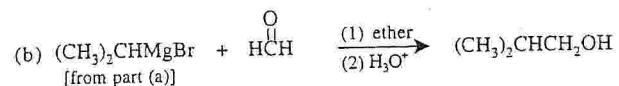
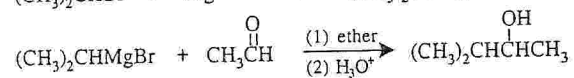
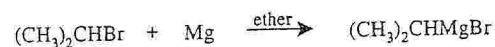
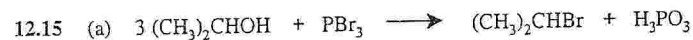
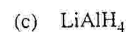
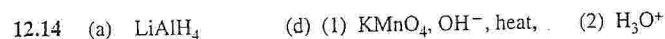
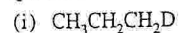


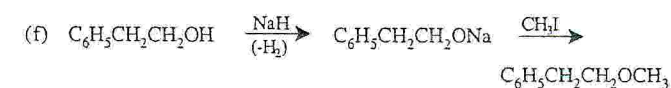
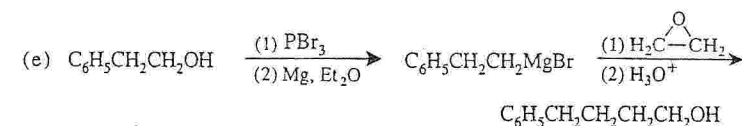
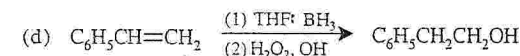
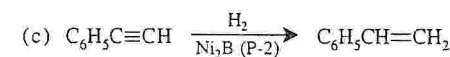
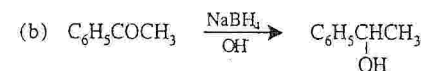
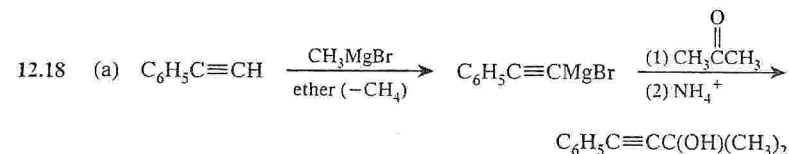
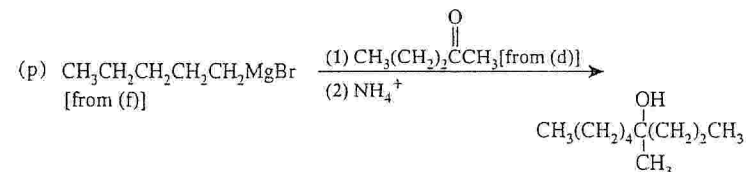
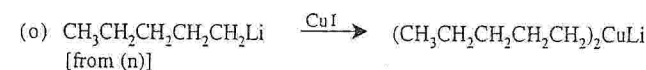
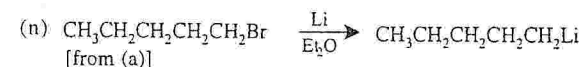
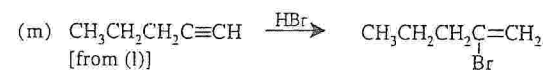
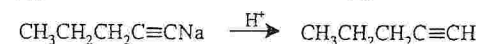
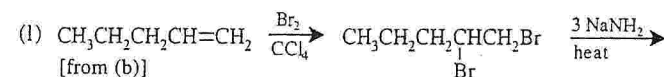
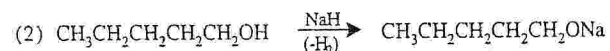
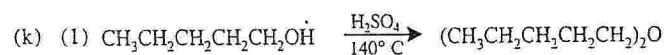
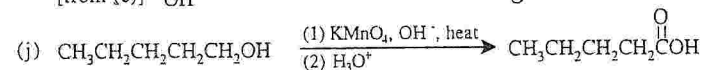
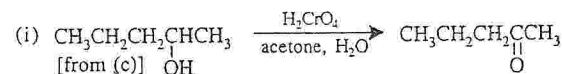
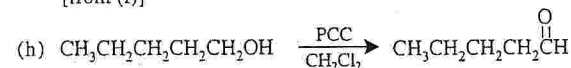
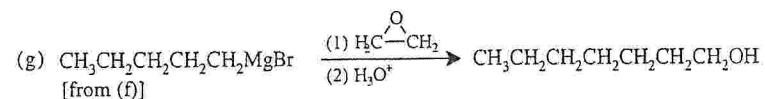
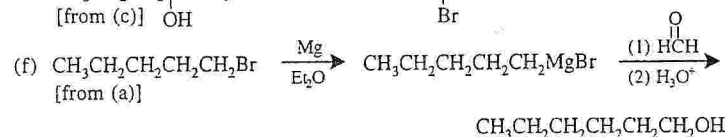
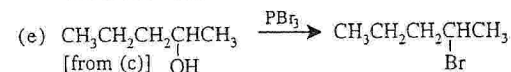
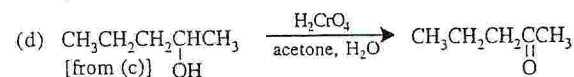
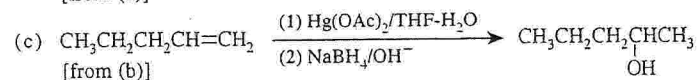
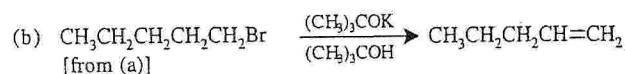
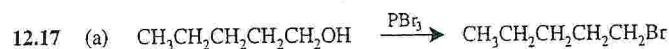
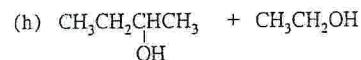
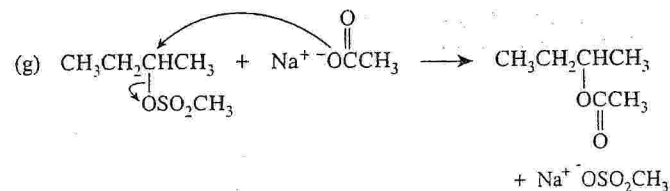


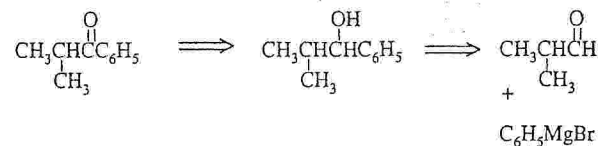
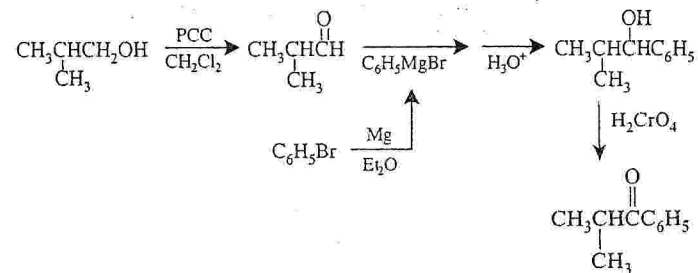
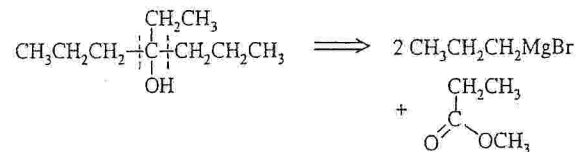
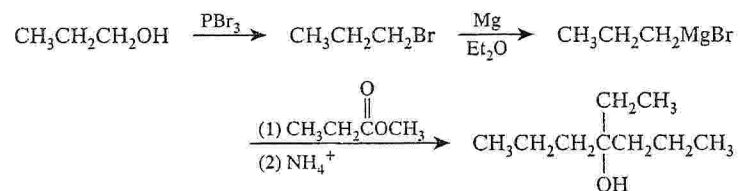
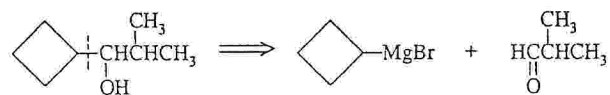
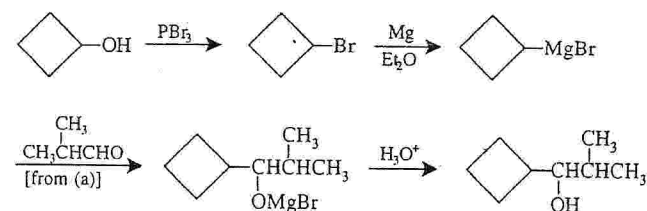
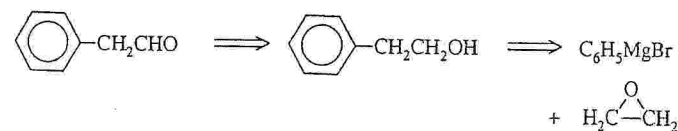
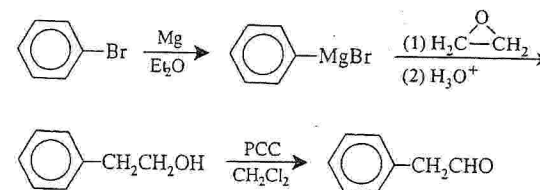
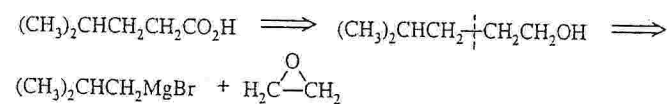
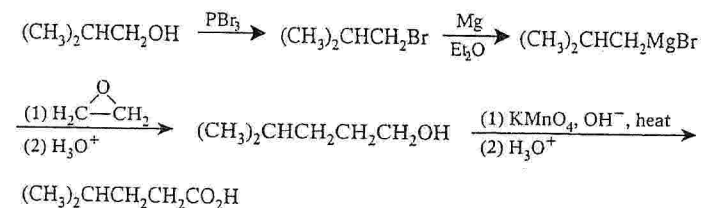


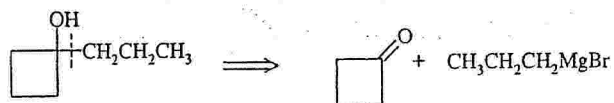
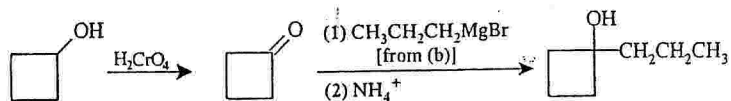
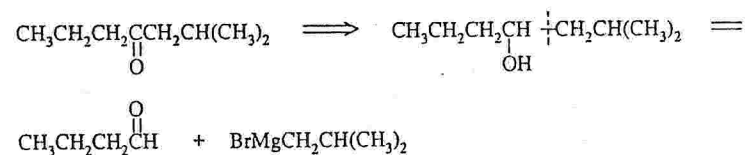
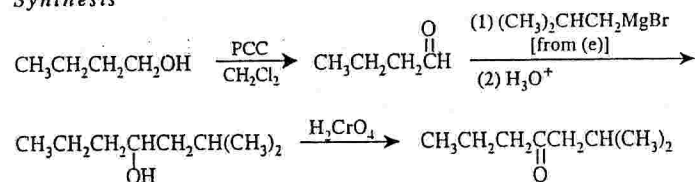
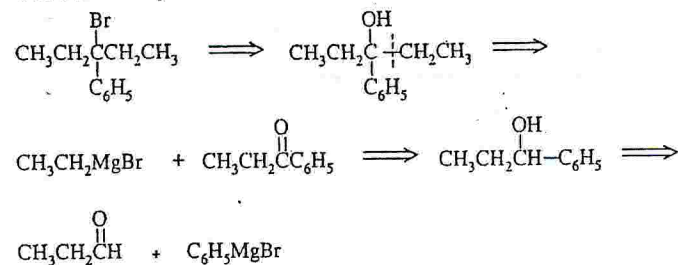
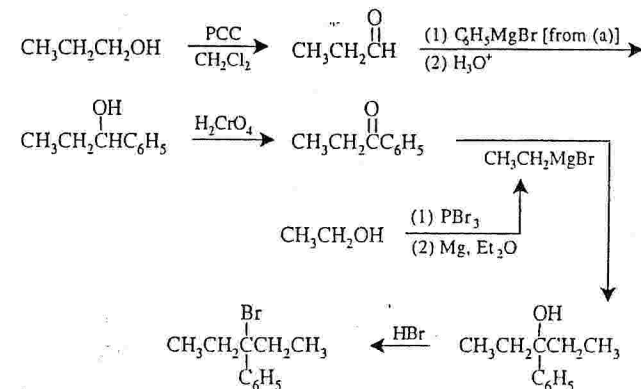
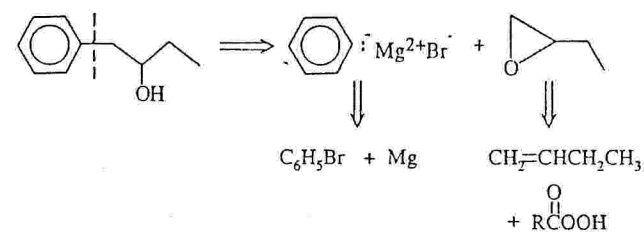
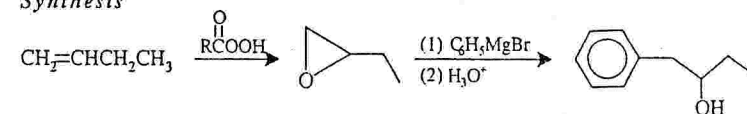


Note: This variation of the Corey-Posner, Whitesides-House synthesis is stereo-specific.

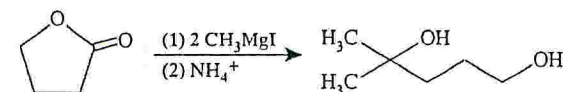




12.19 (a) *Partial Analysis**Synthesis*(b) *Partial Analysis**Synthesis*(c) *Partial Analysis**Synthesis*(d) *Partial Analysis**Synthesis*(e) *Partial Analysis**Synthesis*

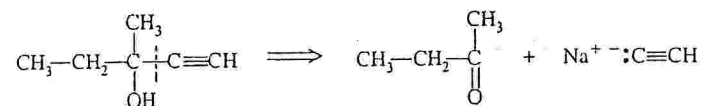
(f) *Partial Analysis**Synthesis*(g) *Partial Analysis**Synthesis*(h) *Partial Analysis**Synthesis*12.20 *Analysis**Synthesis*

12.21 The starting compound is a cyclic ester. Addition of two molar equivalents of  $\text{CH}_3\text{MgI}$  will (after acidification) furnish the desired product.

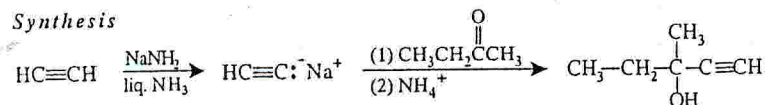




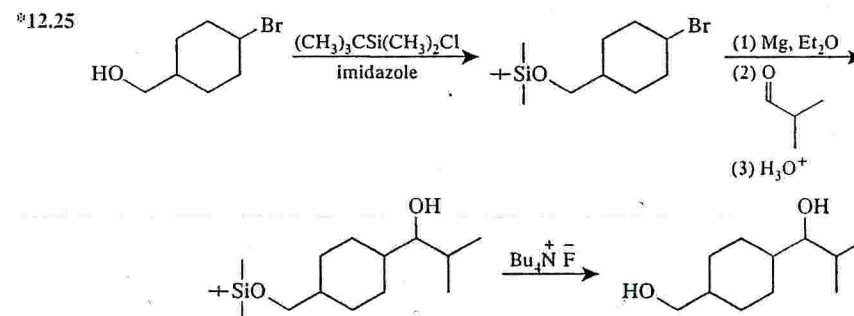
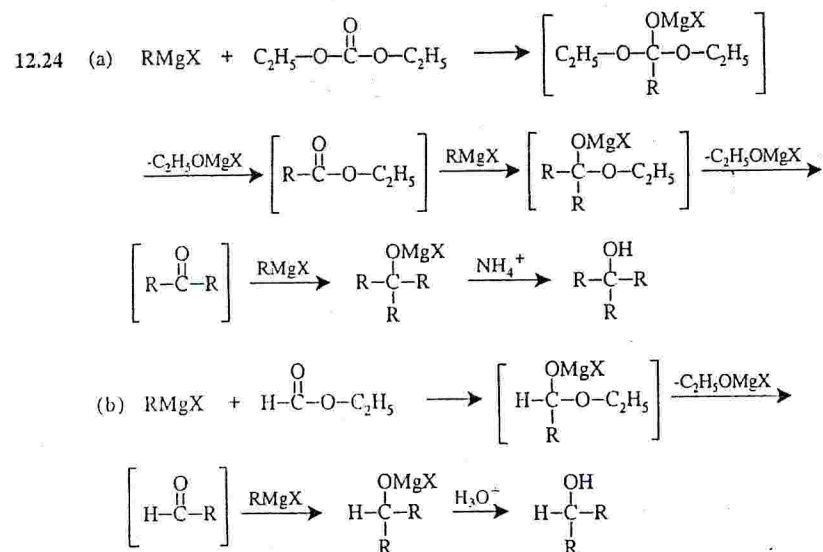
## 12.22 Analysis



## Synthesis



12.23 The three- and four-membered rings are strained, and so they open on reaction with  $\text{RMgX}$  or  $\text{RLi}$ . THF possesses an essentially unstrained ring and hence is far more resistant to attack by an organometallic compound.



Before converting the reactant to a Grignard reagent it is first necessary to mask the alcohol, such as by converting it to a *tert*-butyldimethylsilyl ether. After the Grignard reaction is over the protecting group is removed.

\*12.26 2-Phenylethanol, 1,2-diphenylethanol, and 1,1-diphenylethanol are distinct from diphenylacetic acid and benzyl phenylacetate in that they do not have carbonyl groups. IR spectroscopy can be used to segregate these compounds into two groups according to those that do or do not exhibit carbonyl absorptions.

$^1\text{H}$  NMR can differentiate among all of the compounds. In the case of the alcohols, in the  $^1\text{H}$  NMR spectrum of 2-phenylethanol there will be two triplets of equal integral value, whereas for 1,2-diphenylethanol there will be a doublet and a triplet in a 2:1 area ratio. The triplet will be downfield of the doublet. 1,1-Diphenylethanol will exhibit a singlet for the unsplit methyl hydrogens.

The broadband proton-decoupled  $^{13}\text{C}$  NMR spectrum of 2-phenylethanol should show 6 signals (assuming no overlap), four of which are in the chemical shift region for aromatic carbons. 1,2-Diphenylethanol should exhibit 10 signals (assuming no overlap), 8 of which are in the aromatic region. 1,1-Diphenylethanol should show 6 signals (assuming no overlap), four of which would be in the aromatic region. The DEPT  $^{13}\text{C}$  NMR spectra would give direct evidence as to the number of attached hydrogens on each carbon.

Regarding the carbonyl compounds, both diphenylacetic acid and benzyl phenylacetate will show carbonyl absorptions in the IR, but only the former will also have a hydroxyl absorption. The  $^1\text{H}$  NMR spectrum of diphenylacetic acid should show a broad absorption for the carboxylic acid hydrogen and a sharp singlet for the unsplit hydrogen at C2. Their integral values should be the same, and approximately one tenth the integral value of the signals in the aromatic region. Benzyl phenylacetate will exhibit two singlets, one for each of the unsplit  $\text{CH}_2$  groups. These signals will have an area ratio of 1:5 with respect to the signal for the 10 aromatic hydrogens. The broadband  $^1\text{H}$  decoupled  $^{13}\text{C}$  NMR spectrum for diphenylacetic acid should show four aromatic carbon signals, whereas that for benzyl phenylacetate (assuming no overlapping signals) would show 10 signals in the aromatic carbon region. Aside from the carbonyl and aromatic carbon signals, benzyl phenylacetate would show two additional signals, whereas diphenylacetic acid would show only one. DEPT  $^{13}\text{C}$  NMR spectra for these two compounds would also distinguish them directly.

\*12.27 It makes it impossible to distinguish between aldehyde and ketone type sugars (aldoses and ketoses) that had been components of the saccharide. Also, because the R groups of these sugars contain stereocenters, reduction of the ketone carbonyl will be stereoselective. This will complicate the determination of the ratio of sugars differing in configuration at C2.

\*12.28 The IR indicates the presence of OH and absence of C=C and C=O. The MS indicates a molecular weight of 116 amu and confirms the presence of hydroxyl. The reaction data indicate X contains 2 protons per molecule that are acidic enough to react with a Grignard reagent, meaning two hydroxyl groups per molecule. (This analytical procedure, the Zerewitinoff determination, was routinely done before the advent of NMR.)

Thus X has a partial structure like:

$C_6H_{10}(OH)_2$  with one ring, or

$C_5H_8O(OH)_2$  with two rings, or (less likely)

$C_4H_2O_2(OH)_2$  with three rings.

## QUIZ

12.1 Which of the following could be employed to transform ethanol into  $CH_3CH_2CH_2OH$ ?

(a) Ethanol + HBr, then Mg/diethyl ether, then  $H_3O^+$

(b) Ethanol + HBr, then Mg/diethyl ether, then  $HCHO$ , then  $H_3O^+$

(c) Ethanol +  $H_2SO_4/140^\circ C$

(d) Ethanol + Na, then  $HCHO$ , then  $H_3O^+$

(e) Ethanol +  $H_2SO_4/180^\circ C$ , then  $H_2C=CH_2$

12.2 The principal product(s) formed when 1 mol of methylmagnesium iodide reacts with 1 mol of  $CH_3C(=O)CH_2CH_2OH$ .

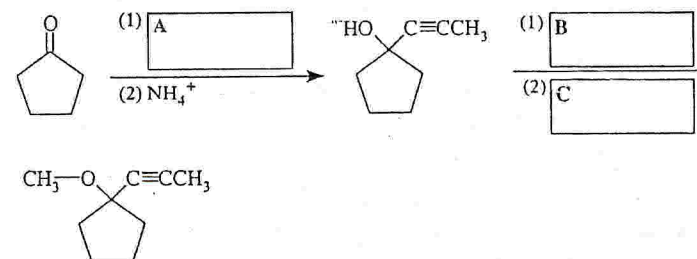
(a)  $CH_4 + CH_3C(=O)CH_2CH_2OMgI$  (d)  $CH_3C(=O)CH_2CH_2OCH_3$

(b)  $CH_3C(OMgI)CH_2CH_2OH$

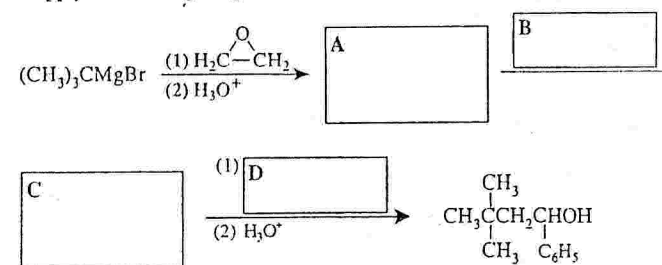
(e) None of the above

(c)  $CH_3C(=O)CH_2CH_2OCH_3$

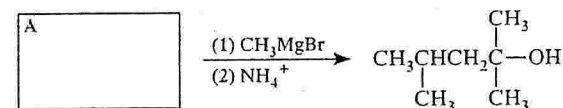
12.3 Supply the missing reagents.



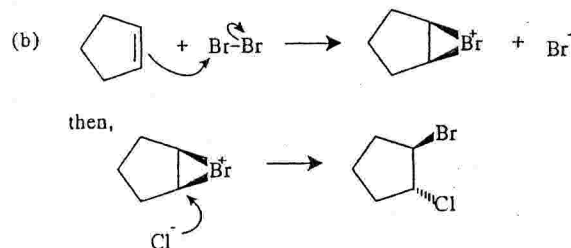
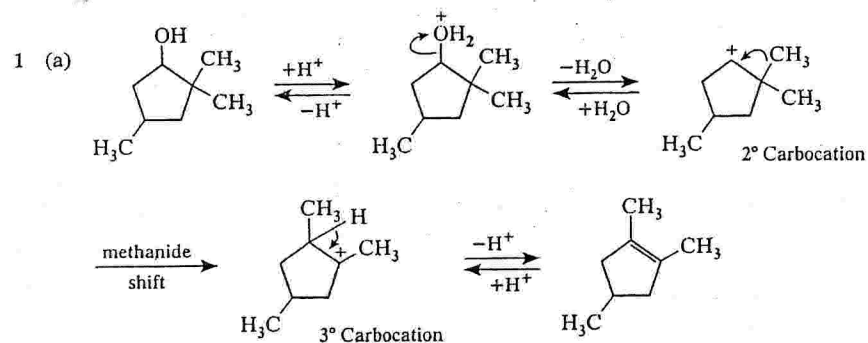
12.4 Supply the missing reagents and intermediates.



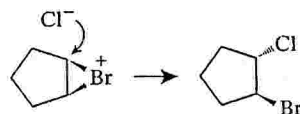
12.5 Supply the missing starting compound.



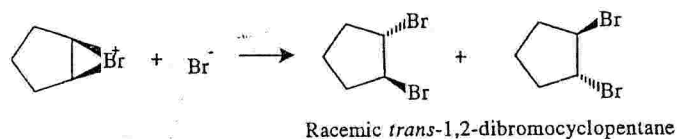
## ANSWERS TO FIRST REVIEW PROBLEM SET



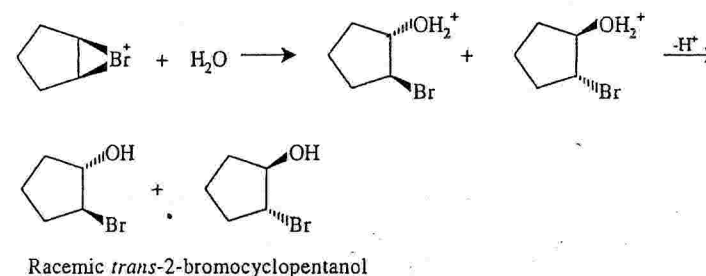
(c) The enantiomer of the product given would be formed in an equimolar amount via the following reaction:



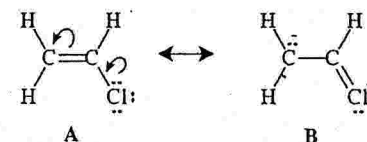
The *trans*-1, 2-dibromocyclopentane would be formed as a racemic form via the reaction of the bromonium ion with a bromide ion:



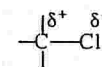
And, *trans*-2-bromocyclopentanol (the bromohydrin) would be formed (as a racemic form) via the reaction of the bromonium ion with water.



- (a)  $\text{CHCl}_3$  (b) The *cis* isomer (c)  $\text{CH}_3\text{Cl}$
- This indicates that the bonds in  $\text{BF}_3$  are geometrically arranged so as to cancel each other's polarities in contrast to the case of  $\text{NF}_3$ . This, together with other evidence, indicates that  $\text{BF}_3$  has trigonal planar structure and  $\text{NF}_3$  has trigonal pyramidal structure.
- (a)  $\text{sp}^3$   
(b) They are much smaller ( $60^\circ$ ) than the expected  $109.5^\circ$ .  
(c) That the bent bonds in cyclopropane, like compressed springs, contain stored energy that is available to assist in reactions that open the 3-membered ring.
- All of these differences can be explained by the contribution to the  $\text{CH}_2=\text{CHCl}$  molecule made by the following A and B resonance structures.



- Because of the contribution made to the hybrid by B, the C-Cl bond of  $\text{CH}_2=\text{CHCl}$  has some double-bond character and is, therefore, shorter than the "pure" single bond of  $\text{CH}_3\text{CH}_2\text{Cl}$ .
- The contribution made to the hybrid by B imparts some single-bond character to the carbon-carbon double bond of  $\text{CH}_2=\text{CHCl}$ , causing it to be longer than the "pure" double bond of  $\text{CH}_2=\text{CH}_2$ .
- Electronegativity differences would cause a carbon-chlorine bond to be polarized as follows:

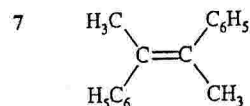
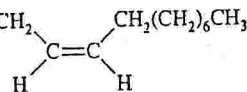
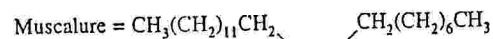
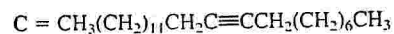
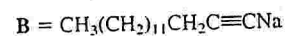
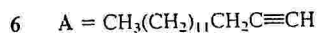




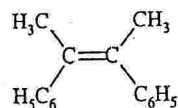
And this effect accounts, almost entirely, for the dipole moment of  $\text{CH}_3\text{CH}_2\text{Cl}$ .



With  $\text{CH}_2=\text{CH}-\text{Cl}$ , however, the resonance contribution of **B** tends to oppose the polarization of the  $\text{C}-\text{Cl}$  bond caused by electronegativity differences. That is, the resonance effect partially cancels the electronegativity effect, causing the dipole moment to be smaller.

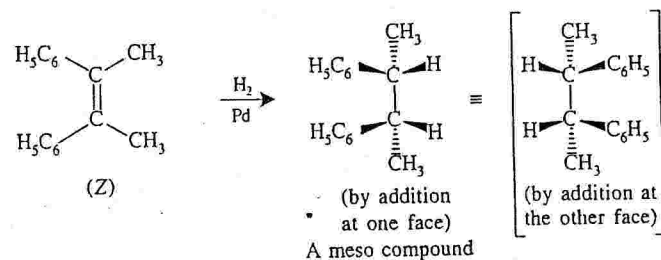


(*E*)-2,3-Diphenyl-2-butene

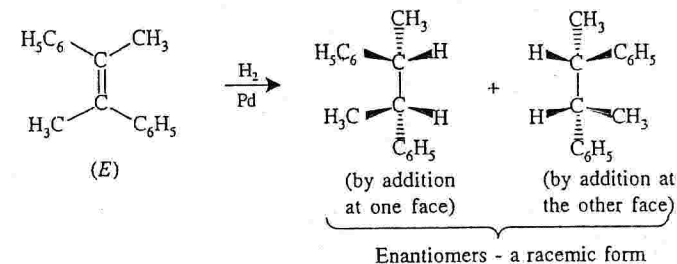


(*Z*)-2,3-Diphenyl-2-butene

Because catalytic hydrogenation is a syn addition, catalytic hydrogenation of the (*Z*) isomer would yield a meso compound.

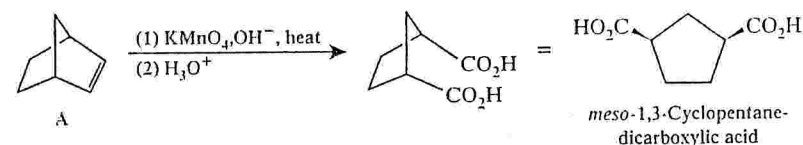


Syn addition of hydrogen to the (*E*) isomer would yield a racemic form:

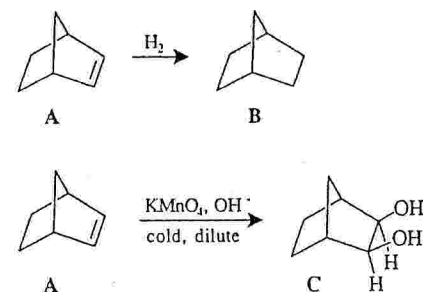


- 8 From the molecular formula of **A** and of its hydrogenation product **B**, we can conclude that **A** has two rings and a double bond. (**B** has two rings.)

From the product of strong oxidation with  $\text{KMnO}_4$  and its stereochemistry (i.e., compound **C**), we can deduce the structure of **A**.

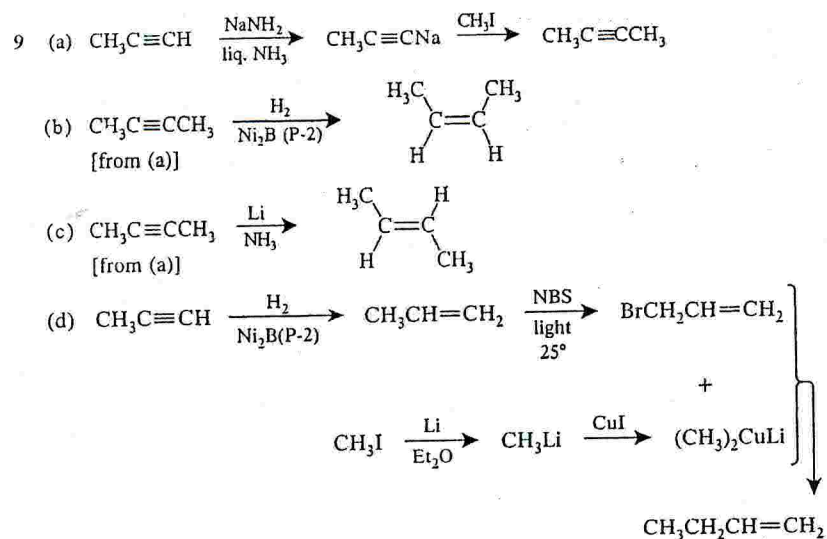


Compound **B** is bicyclo[2.2.1]heptane and **C** is a glycol.

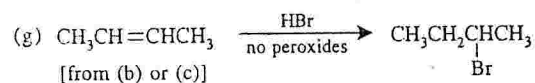
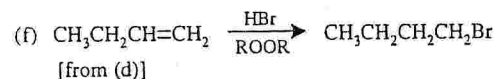
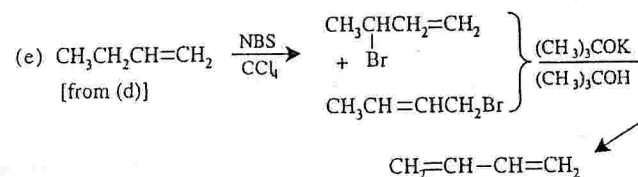
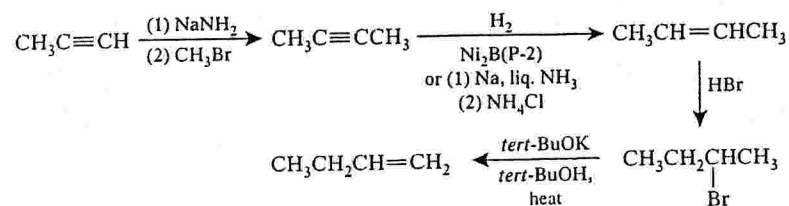


Notice that **C** is also a meso compound.

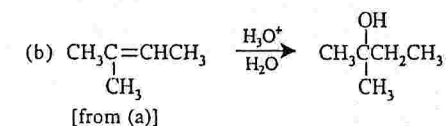
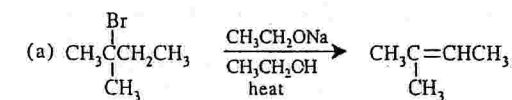
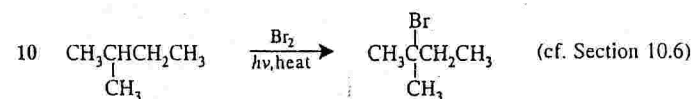
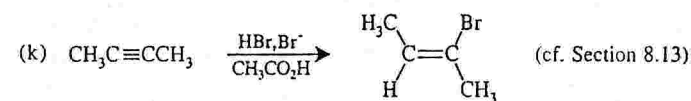
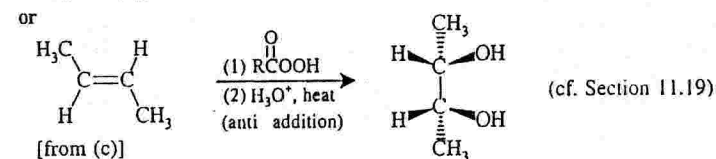
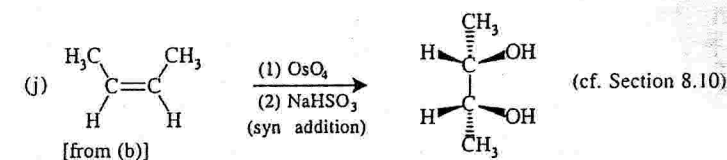
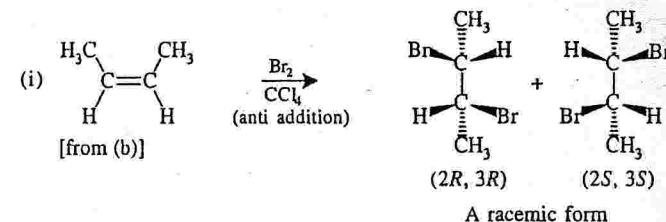
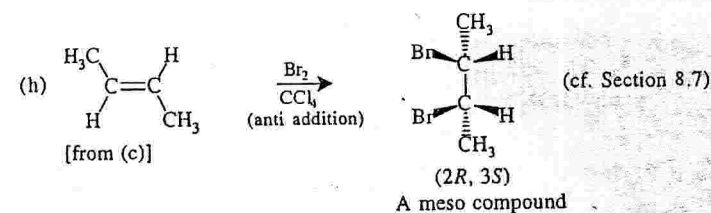
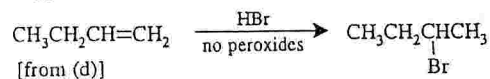


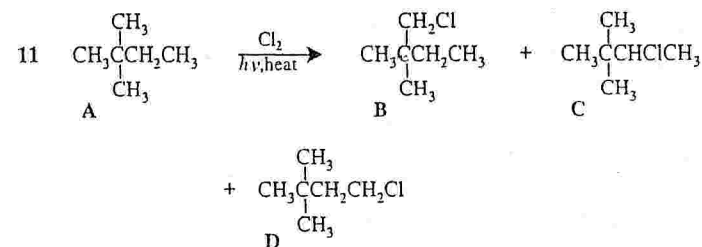
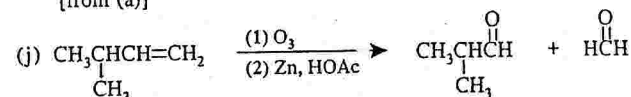
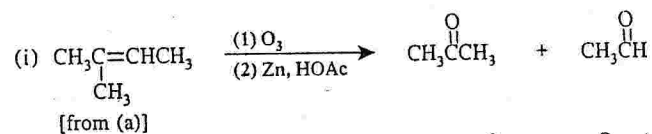
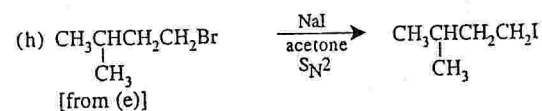
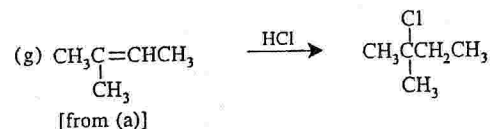
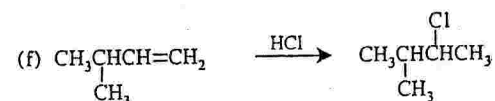
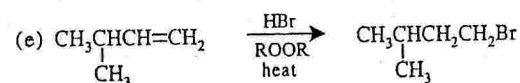
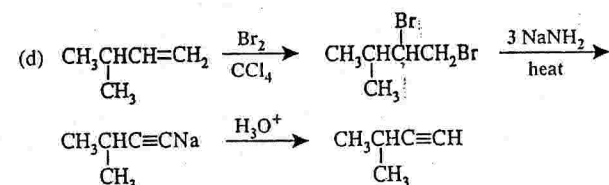
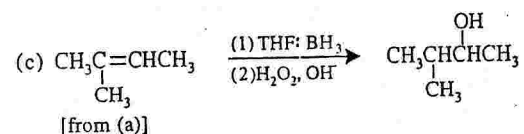


or

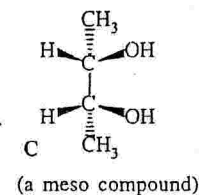
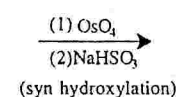
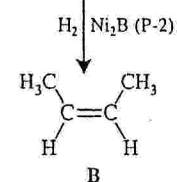
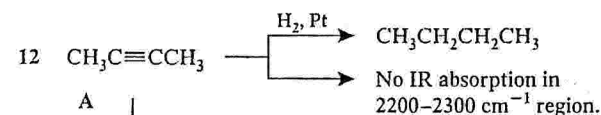
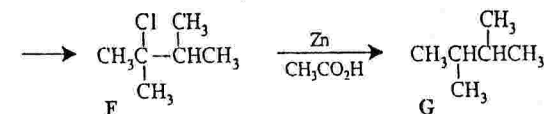
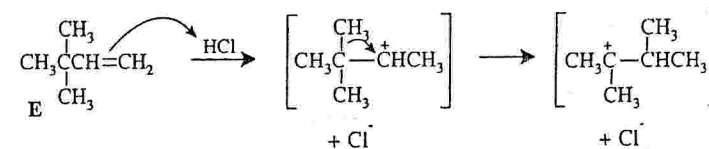
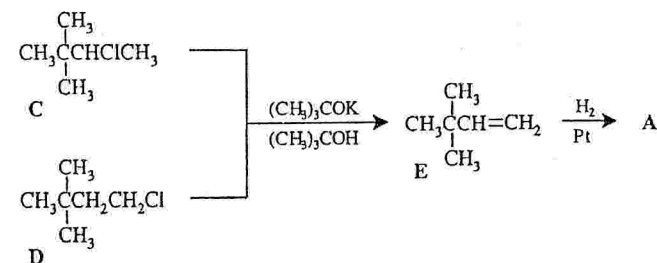


or

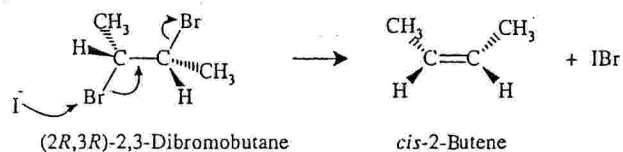
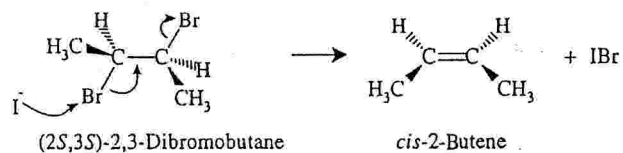
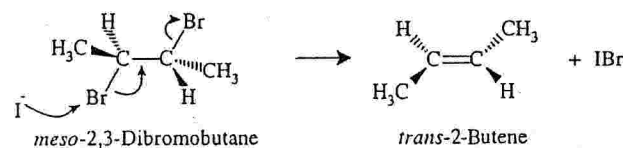




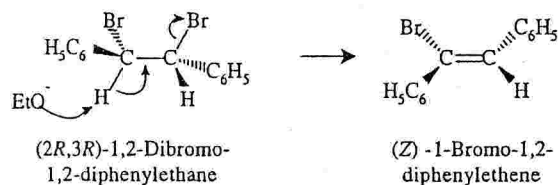
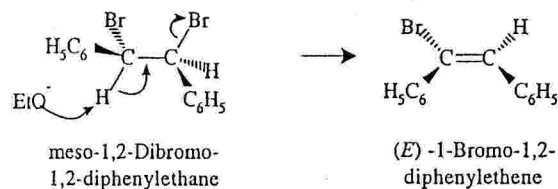
B cannot undergo dehydrohalogenation because it has no  $\beta$  hydrogen; however, C and D can, as shown next.



- 13 The eliminations are anti eliminations, requiring an anti periplanar arrangement of the bromine atoms.

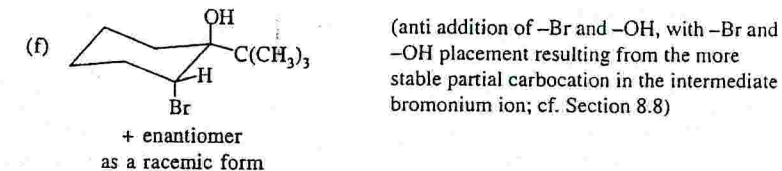
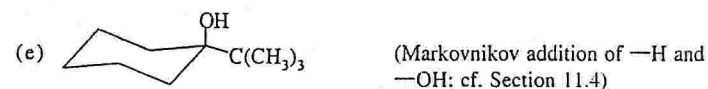
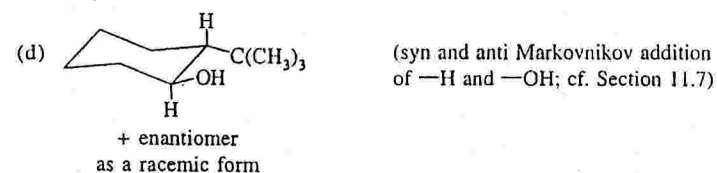
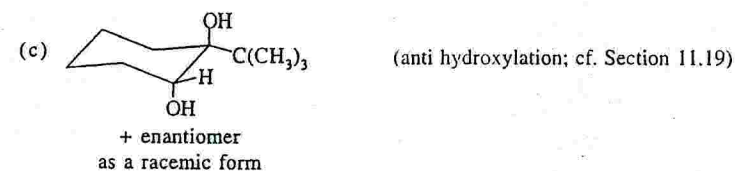
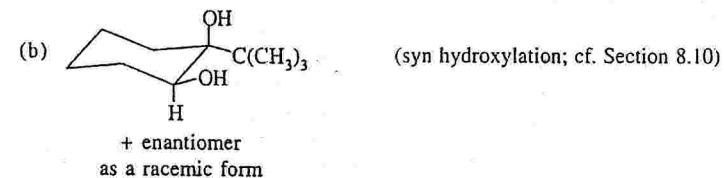
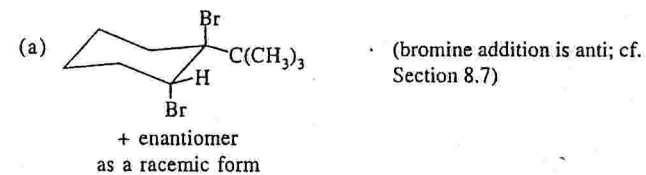


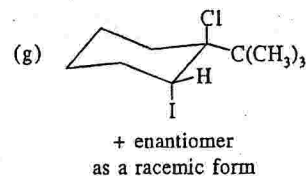
- 14 The eliminations are anti eliminations, requiring an anti periplanar arrangement of the -H and -Br.



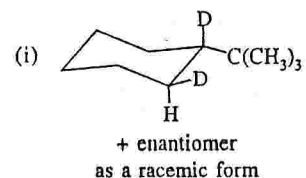
(2*S*,3*S*)-1,2-Dibromo-1,2-diphenylethane will also give (*Z*)-1-bromo-1,2-diphenylethene in an anti elimination.

- 15 In all the following structures, notice that the large *tert*-butyl group is equatorial.

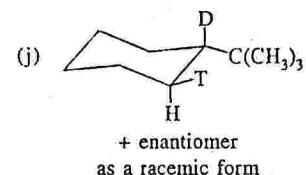




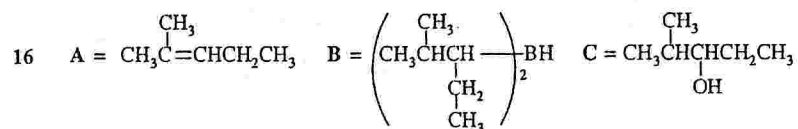
(anti addition of -I and -C(CH<sub>3</sub>)<sub>3</sub>, following Markovnikov's rule; cf. Section 8.2)



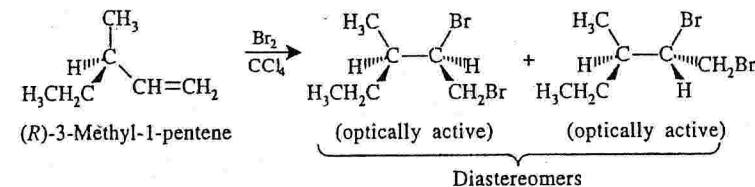
(syn addition of deuterium; cf. Section 7.14)



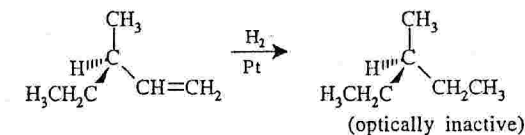
(syn, anti Markovnikov addition of -D and -B-, with -B- being replaced by -I where it stands; cf. Section 11.7)



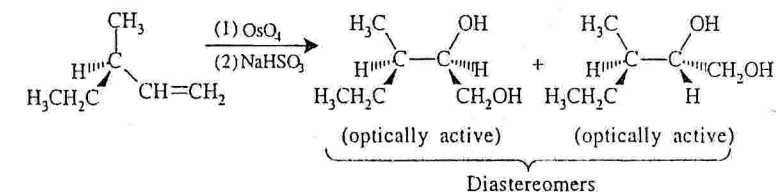
- 17 (a) The following products are diastereomers. They would have different boiling points and would be in separate fractions. Each fraction would be optically active.



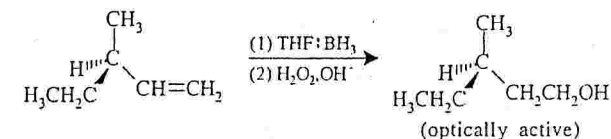
- (b) Only one product is formed. It is achiral, and, therefore, it would not be optically active.



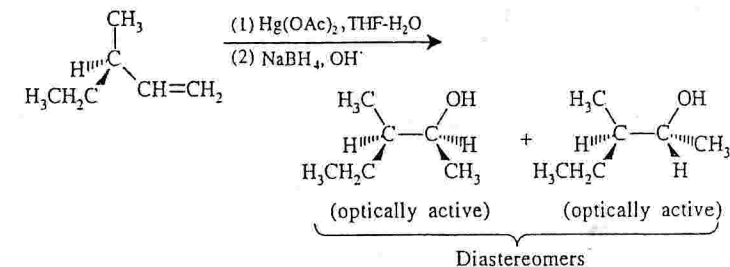
- (c) Two diastereomeric products are formed. Two fractions would be obtained. Each fraction would be optically active.



- (d) One optically active compound is produced.

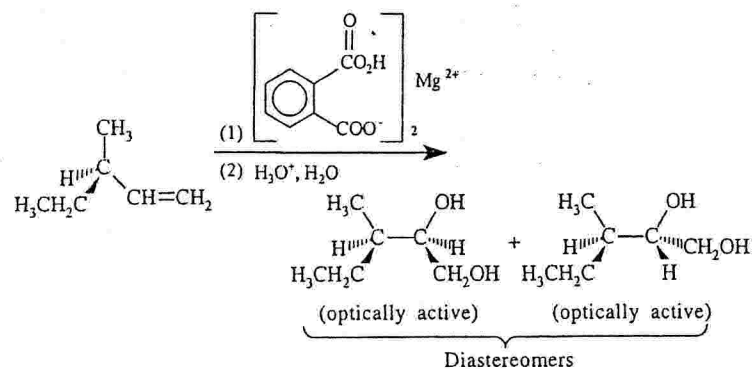


- (e) Two diastereomeric products are formed. Two fractions would be obtained. Each fraction would be optically active.

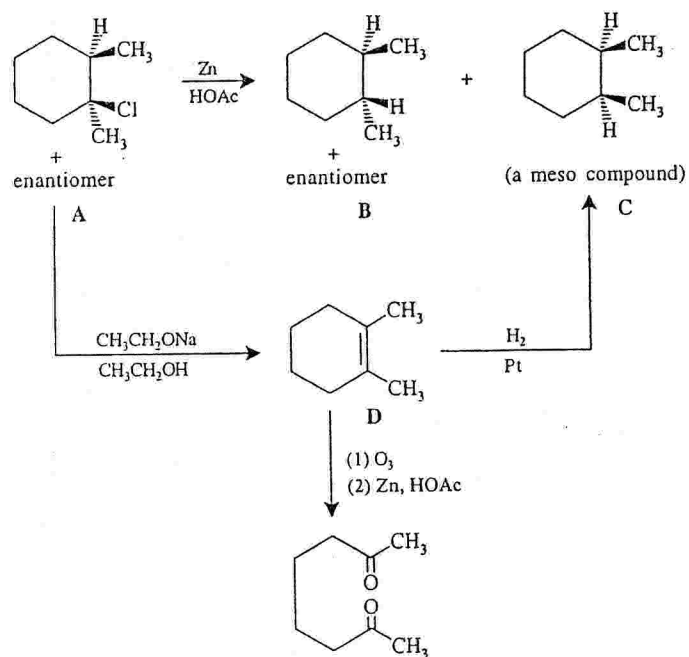




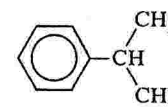
(f) Two diastereomeric products are formed. Two fractions would be obtained. Each fraction would be optically active.



18



19

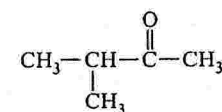


$m/z$  120 =  $M^+$   
 $105 = M^+ - 15(\text{CH}_3 \cdot) = \text{C}_6\text{H}_5-\dot{\text{C}}\text{HCH}_3$   
 $77 = M^+ - 43(i\text{-Pr} \cdot) = \text{C}_6\text{H}_5 +$

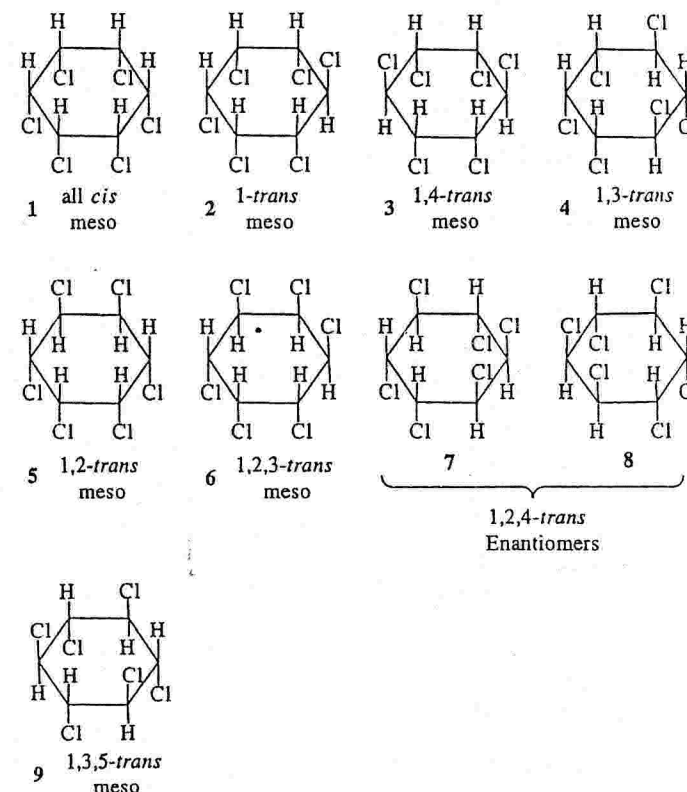
$\delta$  7.2–7.6 5 ring protons  
 2.95 CH of isopropyl group  
 1.29 equivalent  $\text{CH}_3$ s of isopropyl group

20

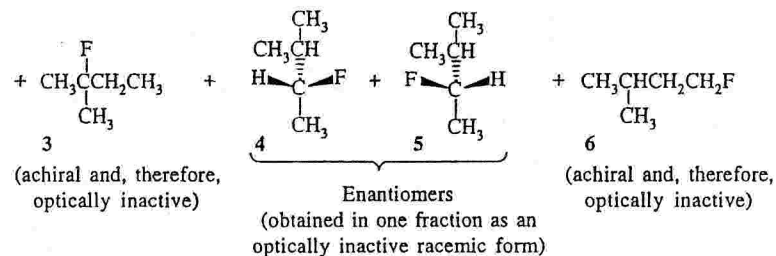
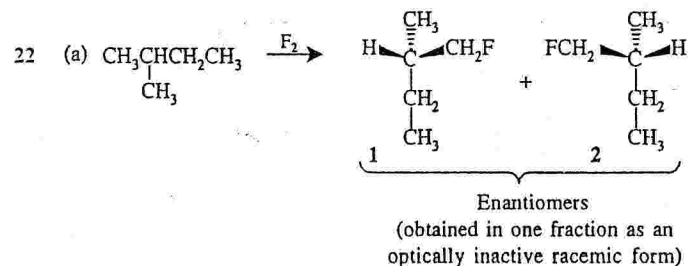
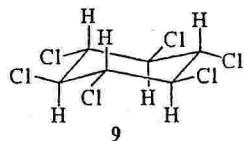
$\text{C}_5\text{H}_{10}\text{O}$  has IHD = 2  
 IR absorption indicates  $\text{C}=\text{O}$   
 $^{13}\text{C}$  NMR spectrum for X is consistent with structure



21 (a)



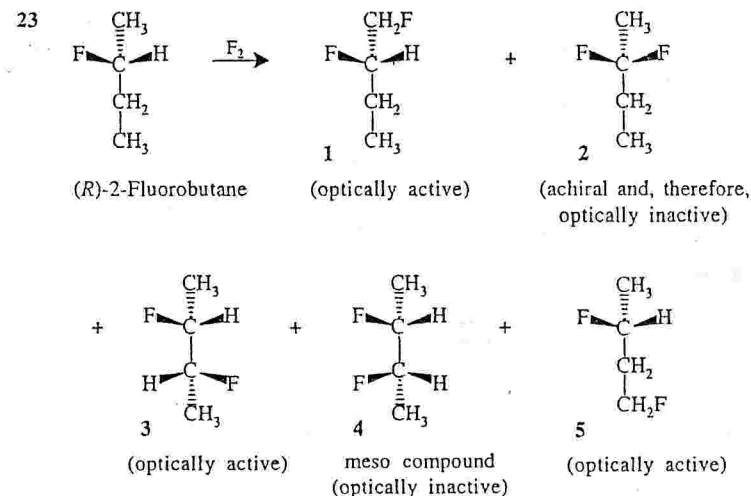
(b) Isomer 9 is slow to react in an E2 reaction because in its more stable conformation (see following structure) all the chlorine atoms are equatorial and an anti periplanar transition state cannot be achieved. All other isomers 1-8 can have a -Cl axial and thus achieve an anti periplanar transition state.



(b) Four fractions. The enantiomeric pairs would not be separated by fractional distillation because enantiomers have the same boiling points.

(c) All of the fractions would be optically inactive.

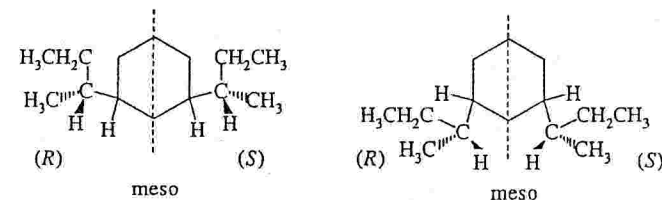
(d) The fraction containing 1 and 2 and the fraction containing 4 and 5.



(b) Five. Compounds 3 and 4 are diastereomers. All others are constitutional isomers of each other.

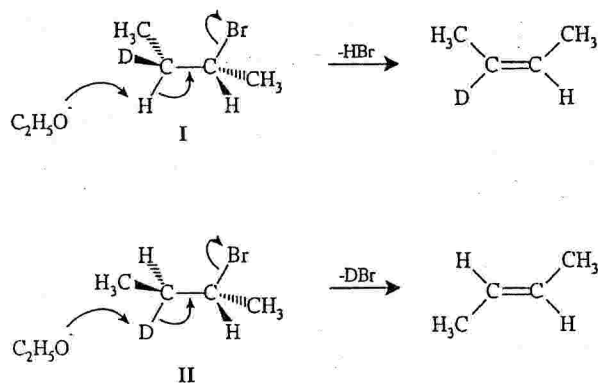
(c) See above.

24



Each of the two structures just given has a plane of symmetry (indicated by the dashed line), and, therefore, each is a meso compound. The two structures are not superposable one on the other; therefore, they represent molecules of different compounds and are diastereomers.

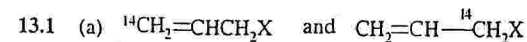
- 25 Only a proton or deuteron anti to the bromine can be eliminated; that is, the two groups undergoing elimination (H and Br or D and Br) must lie in an anti periplanar arrangement. The two conformations of *erythro*-2-bromobutane-3-*d* in which a proton or deuteron is anti periplanar to the bromine are **I** and **II**.



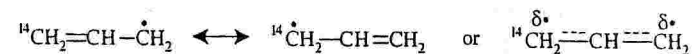
Conformation I can undergo loss of HBr to yield *cis*-2-butene-2-*d*. Conformation II can undergo loss of DBr to yield *trans*-2-butene.

# 13 CONJUGATED UNSATURATED SYSTEMS

## SOLUTIONS TO PROBLEMS

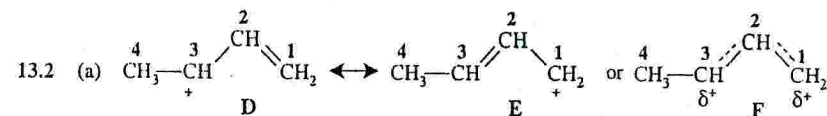


- (b) The reaction proceeds through the resonance-stabilized radical.

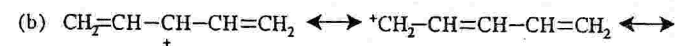
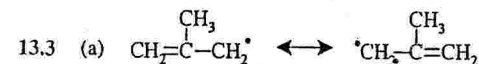
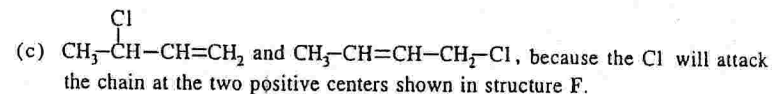


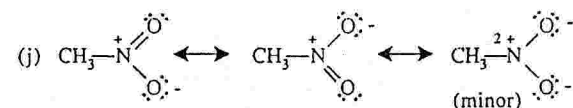
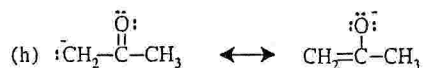
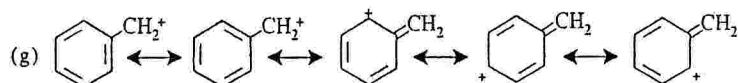
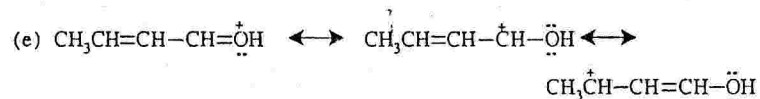
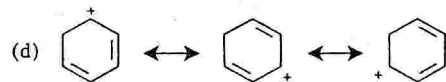
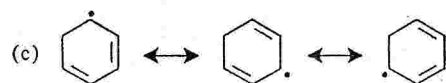
Thus, attack on  $X_2$  can occur by the carbon atom at either end of the chain since these atoms are equivalent.

- (c) 50:50 because attack at the two ends of the chain is equally probable.

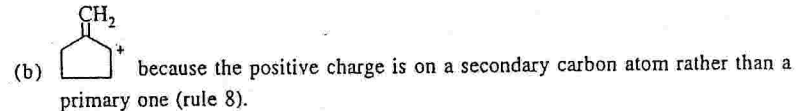


- (b) We know that the allylic cation is almost as stable as a tertiary carbocation. Here we find not only the resonance stabilization of an allylic cation but also the additional stabilization that arises from contributor D in which the plus charge is on a secondary carbon atom.

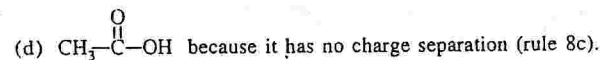




- 13.4 (a)  $\text{CH}_3\text{CH}_2\text{C}^+(\text{CH}_3)-\text{CH}=\text{CH}_2$  because the positive charge is on a tertiary carbon atom rather than a primary one (rule 8).



- (c)  $\text{CH}_2=\text{N}(\text{CH}_3)_2$  because all atoms have a complete octet (rule 8b), and there are more covalent bonds (rule 8a).



- (e)  $\text{CH}_2=\dot{\text{C}}\text{HCH}=\text{CH}_2$  because the radical is on a secondary carbon atom rather than a primary one (rule 8).

- (f)  $:\text{NH}_2-\text{C}\equiv\text{N}:$  because it has no charge separation (rule 8c).

- 13.5 In resonance structures, the positions of the nuclei must remain the same for all structures (rule 2). The keto and enol forms shown differ not only in the positions of their electrons, but also in the position of one of the hydrogen atoms. In the enol form, it is attached to an oxygen atom; in the keto form, it has been moved so that it is attached to a carbon atom.

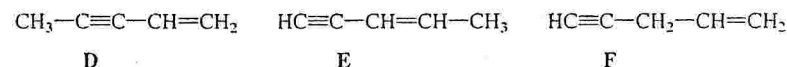
- 13.6 (a) *cis*-1,3-Pentadiene, *trans,trans*-2,4-hexadiene, *cis,trans*-2,4-hexadiene, and 1,3-cyclohexadiene are conjugated dienes.

- (b) 1,4-Cyclohexadiene and 1,4-pentadiene are isolated dienes.

- (c) 1-Penten-4-yne is an isolated enyne.

- 13.7 The formula,  $\text{C}_6\text{H}_8$ , tells us that A and B have six hydrogen atoms less than an alkane. This unsaturation may be due to three double bonds, one triple bond and one double bond, or combinations of two double bonds and a ring, or one triple bond and a ring. Since both A and B react with 2 mol of  $\text{H}_2$  to yield cyclohexane, they are either cyclohexyne or cyclohexadienes. The absorption maximum of 256 nm for A tells us that it is conjugated. Compound B, with no absorption maximum beyond 200 nm, possesses isolated double bonds. We can rule out cyclohexyne because of ring strain caused by the requirement of linearity of the  $-\text{C}\equiv\text{C}-$  system. Therefore, A is 1,3-cyclohexadiene; B is 1,4-cyclohexadiene.

- 13.8 All three compounds have an unbranched five-carbon chain, because the product of hydrogenation is unbranched pentane. The formula,  $\text{C}_5\text{H}_6$ , suggests that they have one double bond and one triple bond. Compounds D, E, and F must differ, therefore, in the way the multiple bonds are distributed in the chain. Compounds E and F have a terminal  $-\text{C}\equiv\text{CH}$  [IR absorption at  $\sim 3300\text{ cm}^{-1}$ ]. The UV absorption maximum near 230 nm for D and E suggests that in these compounds, the multiple bonds are conjugated. The structures are

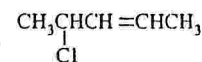


- 13.9 (a) Recall that 1,2 and 1,4 addition refer to the conjugated system itself and not the entire carbon chain.  $\text{CH}_3\text{CH}_2\text{CH}(\text{Cl})=\text{CHCH}_3$  and  $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}(\text{Cl})\text{CH}_3$

- (b) The most stable cation is a hybrid of equivalent forms:

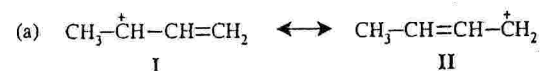


Thus, 1,4 and 1,2 addition yield the same product.





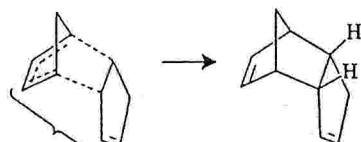
13.10 Addition of the proton gives the resonance hybrid.



The inductive effect of the methyl group in I stabilizes the positive charge on the adjacent carbon. Such stabilization of the positive charge does not occur in II. Because I contributes more heavily to the resonance hybrid than does II, C2 bears a greater positive charge and reacts faster with the bromide ion.

(b) In the 1,4-addition product, the double bond is more highly substituted than in the 1,2-addition product; hence it is the more stable alkene.

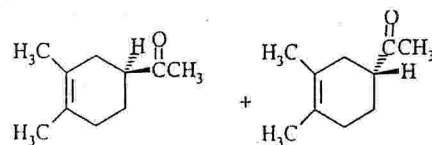
13.11 (a), (c)



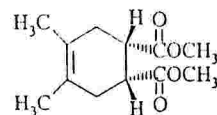
(b)  $\pi$ -Electron interaction occurs here.

Endo adduct

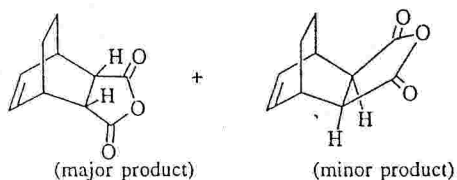
13.12 (a)



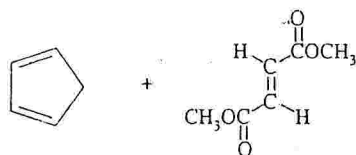
(b)



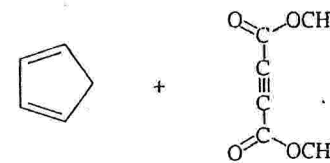
(c)



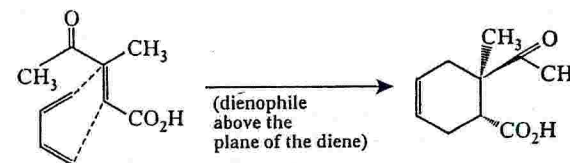
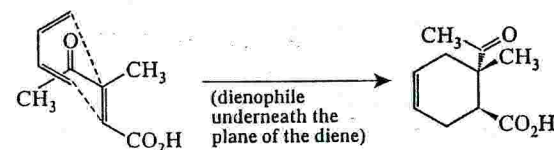
13.13 Use the trans diester because the stereochemistry is retained in the adduct.



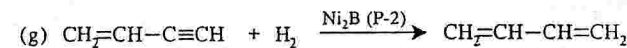
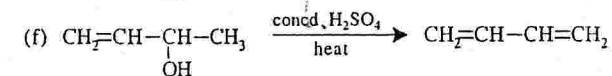
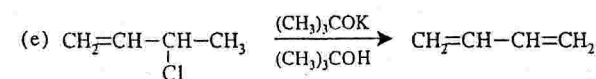
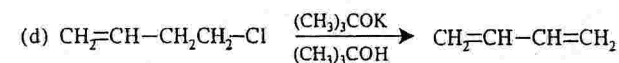
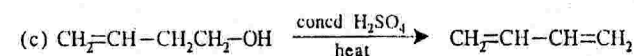
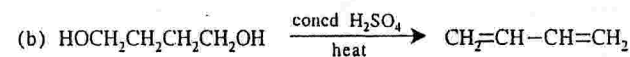
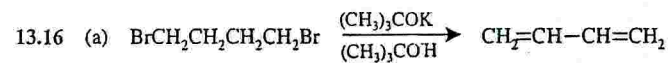
13.14



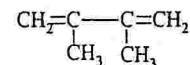
13.15

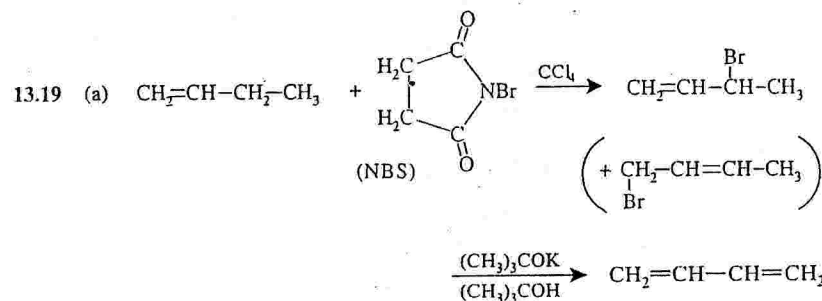
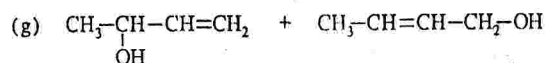
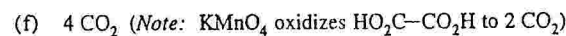
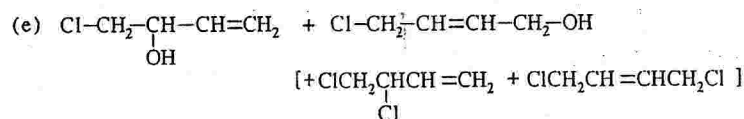
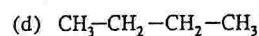
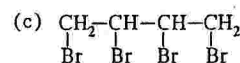
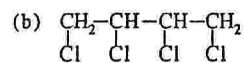
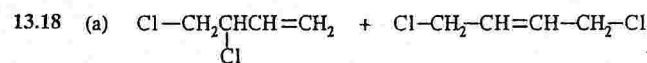


(Or, in each case, the other face of the dienophile could present itself to the diene, resulting in the respective enantiomer.)

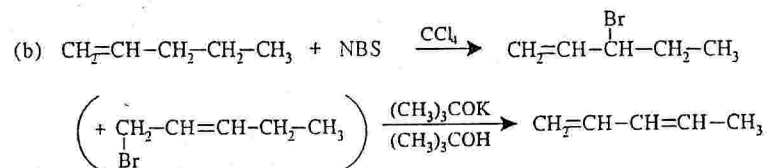


13.17

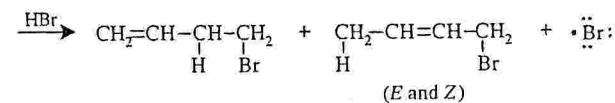
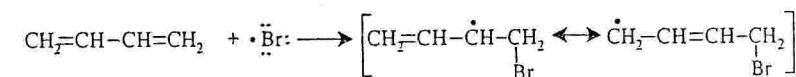
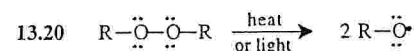
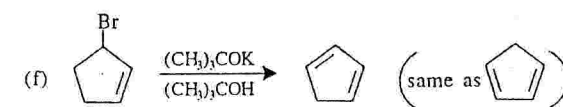
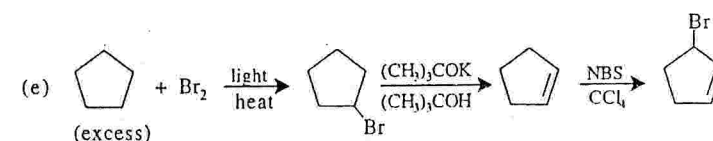
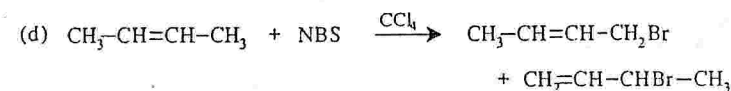
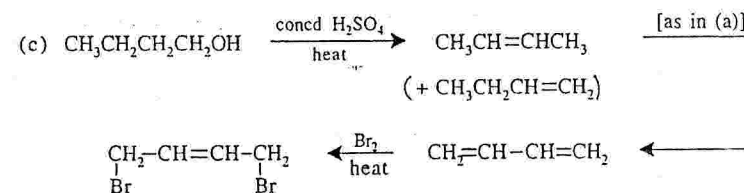




Note: In the second step, both allylic halides undergo elimination of  $\text{HBr}$  to yield 1,3-butadiene; therefore, separating the mixture produced in the first step is unnecessary. The  $\text{BrCH}_2\text{CH}=\text{CHCH}_3$  undergoes a 1,4 elimination (the opposite of a 1,4 addition).

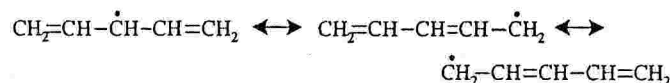


Here again both products undergo elimination of  $\text{HBr}$  to yield 1,3-pentadiene.

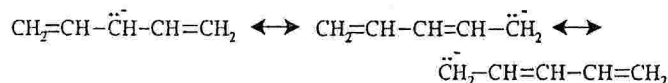


13.21 Various IR,  $^1\text{H}$  NMR,  $^{13}\text{C}$  NMR, and MS features could be used to differentiate the members of any of these pairs. IR absorptions can be used to indicate whether double or triple bonds are present in a given molecule, or whether a hydroxyl group or halogen is present. Chemical shifts in the proton and carbon NMR spectra indicated can also be used to indicate the hybridization state of carbon atoms. The number of signals in the proton or carbon NMR spectrum for a given compound can suggest whether there is symmetry to the structure or not. Splitting patterns in the proton spectra can give detailed information about the connectivity of atoms. Mass spectra will indicate molecular weight differences when the molecular ions are present. Fragmentation patterns can indicate specific aspects of molecular structure characteristic to one member of a pair or another. UV would distinguish members of a pair where one is conjugated and the other is not. Consult tables with representative spectral information to predict specific aspects of the spectra for each compound.

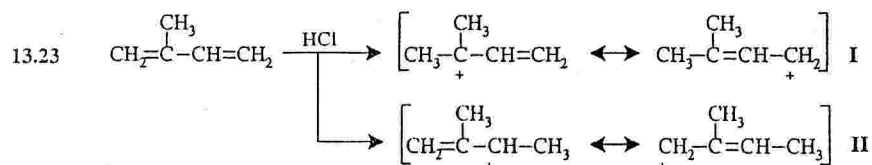
13.22 (a) Because a highly resonance-stabilized radical is formed:



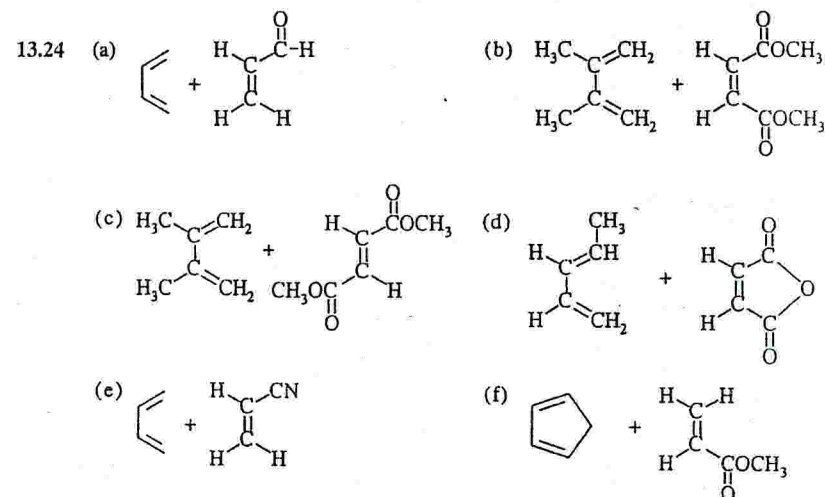
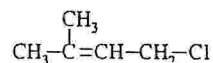
(b) Because the carbanion is more stable:



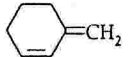
That is, we can write more resonance structures of nearly equal energies.

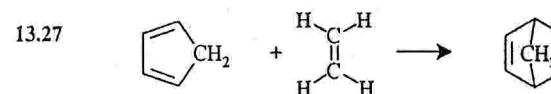
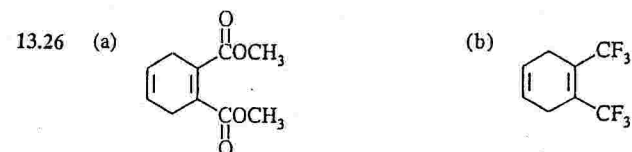


The resonance hybrid, I, has the positive charge, in part, on the tertiary carbon atom; in II, the positive charge is on primary and secondary carbon atoms only. Therefore, hybrid I is more stable and will be the intermediate carbocation. A 1,4 addition to I gives



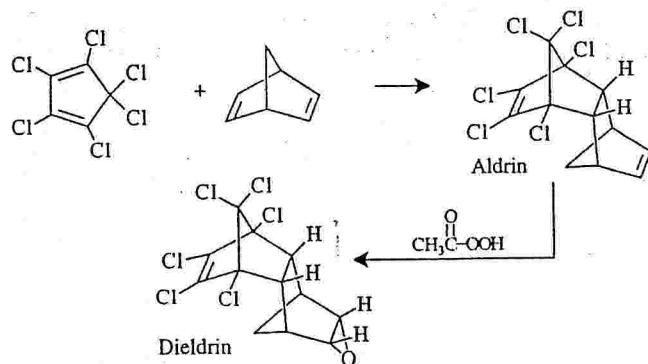
13.25 Neither compound can assume the s-cis conformation. 1,3-Butadiyne is linear, and

 is held in an s-trans conformation by the requirements of the ring.

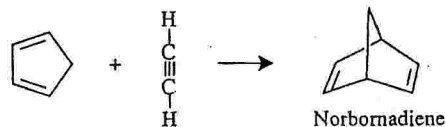


13.28 The endo adduct is less stable than the exo, but is produced at a faster rate at  $25^\circ\text{C}$ . At  $90^\circ\text{C}$  the Diels-Alder reaction becomes reversible; an equilibrium is established, and the more stable exo adduct predominates.

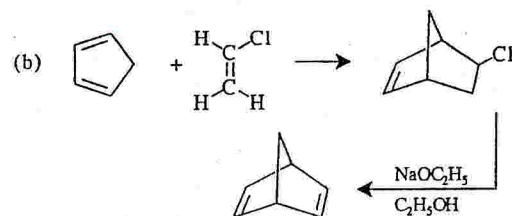
13.29



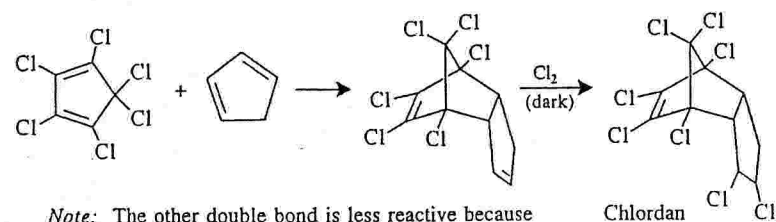
13.30 (a)



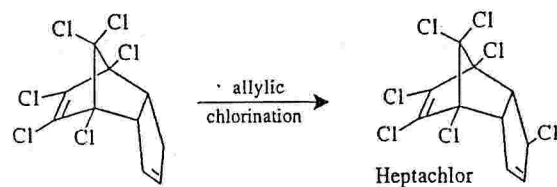
(b)



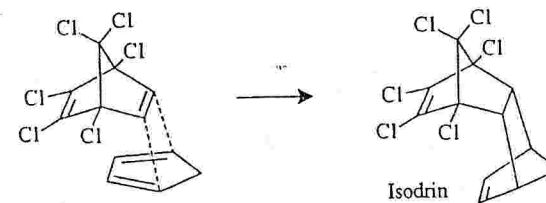
13.31



Note: The other double bond is less reactive because of the presence of the two chlorine substituents.

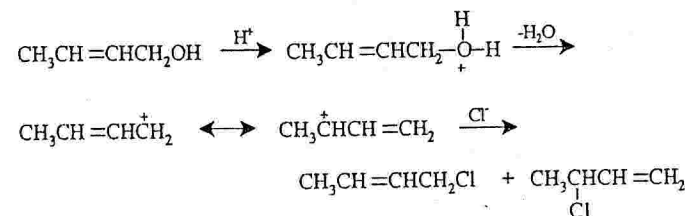


13.32

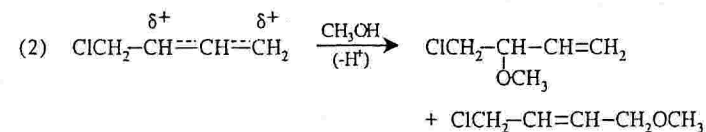
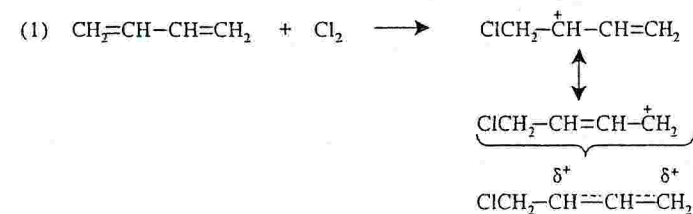


13.33

Protonation of the alcohol and loss of water lead to an allylic cation that can react with a chloride ion at either C1 or C3.

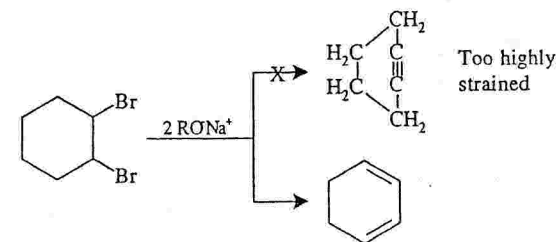


13.34



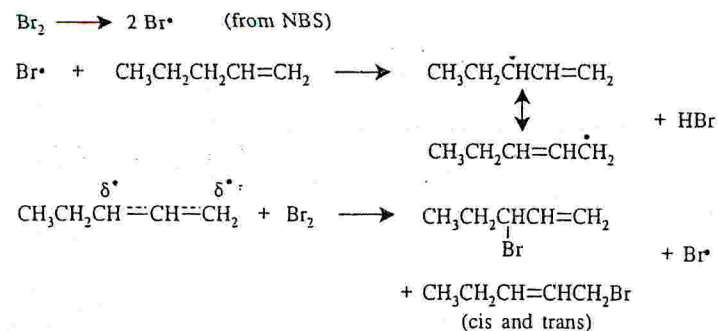
13.35

A six-membered ring cannot accommodate a triple bond because of the strain that would be introduced.

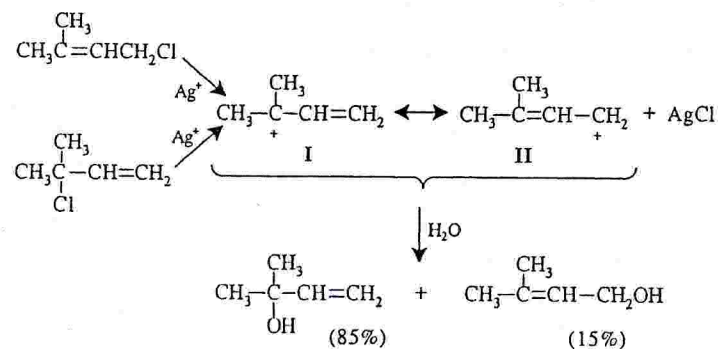




- 13.36 The products are  $\text{CH}_3\text{CH}_2\text{CH}(\text{Br})\text{CH}=\text{CH}_2$  and  $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{Br}$  (cis and trans). They are formed from an allylic radical in the following way:

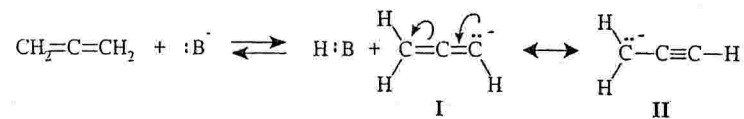


- 13.37 (a) The same carbocation (a resonance hybrid) is produced in the dissociation step:

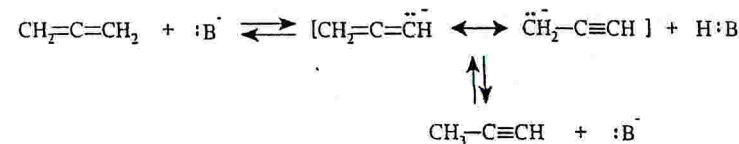


(b) Structure I contributes more than II to the resonance hybrid of the carbocation (rule 8). Therefore, the hybrid carbocation has a larger partial positive charge on the tertiary carbon atom than on the primary carbon atom. Reaction of the carbocation with water will therefore occur more frequently at the tertiary carbon atom.

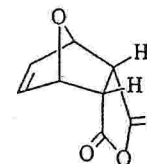
- 13.38 (a) Propyne. (b) Base ( $\text{B}^-$ ) removes a proton, leaving the anion whose resonance structures are shown:



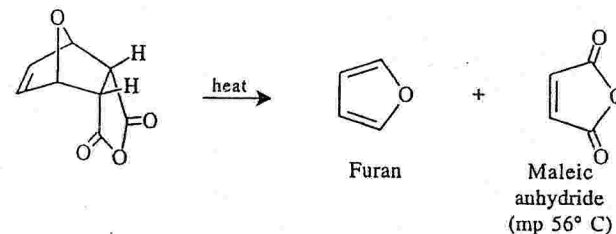
Reaction with  $\text{H}:\text{B}$  may then occur at the  $\text{CH}_2$  carbanion. The overall reaction is



- 13.39 The first crystalline solid is the Diels-Alder adduct below, mp  $125^\circ\text{C}$ ,



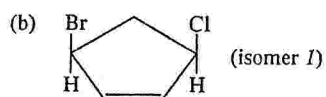
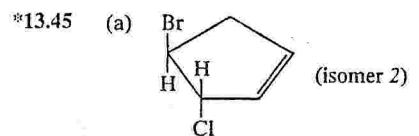
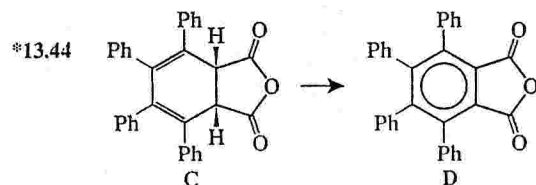
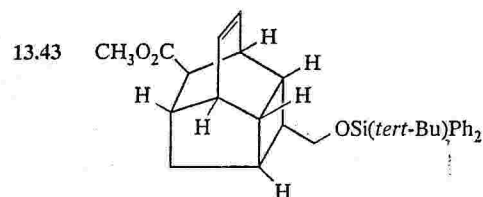
On melting, this adduct undergoes a reverse Diels-Alder reaction, yielding furan (which vaporizes) and maleic anhydride, mp  $56^\circ\text{C}$ ,



- 13.40 (a) + enantiomer (b) + enantiomer
- (c) + enantiomer (d) + enantiomer

- 13.41 The product formed when butyl bromide undergoes elimination is 1-butene, a simple monosubstituted alkene. When 4-bromo-1-butene undergoes elimination, the product is 1,3-butadiene, a conjugated diene, and therefore, a more stable product. The transition states leading to the products reflect the relative stabilities of the products. Since the transition state leading to 1,3-butadiene has the lower free energy of activation of the two, the elimination reaction of 4-bromo-1-butene will occur more rapidly.

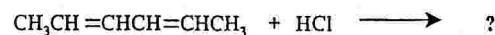
- 13.42 The diene portion of the molecule is locked into an *s*-trans conformation. It cannot, therefore, achieve the *s*-cis conformation necessary for a Diels-Alder reaction.

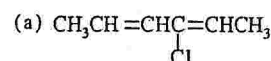
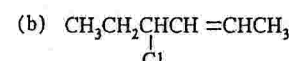
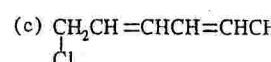
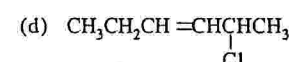
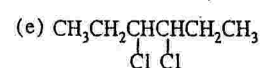


(c) See above

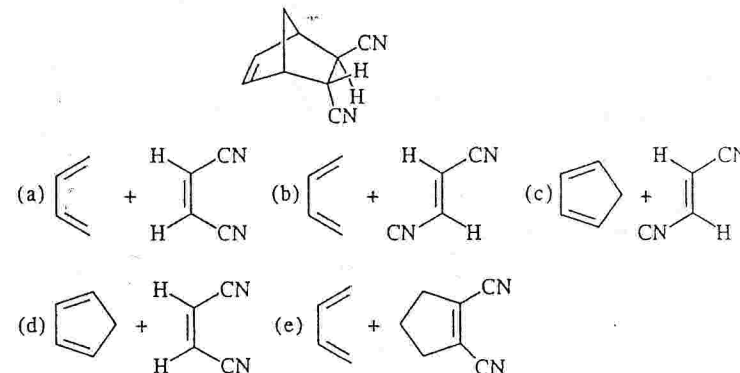
## QUIZ

- 13.1 Give the 1,4-addition product of the following reaction:

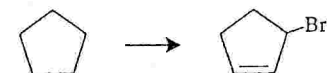


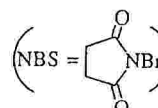
- (a)  (b)   
 (c)  (d)   
 (e) 

- 13.2 Which diene and dienophile could be used to synthesize the following compound?



- 13.3 Which reagent(s) could be used to carry out the following reaction?



- (a) NBS/ $\text{CCl}_4$  (NBS = ) (b) NBS/ $\text{CCl}_4$ , then  $\text{Br}_2/h\nu$   
 (c)  $\text{Br}_2/h\nu$ , then  $(\text{CH}_3)_3\text{COK}/(\text{CH}_3)_3\text{COH}$ , then NBS/ $\text{CCl}_4$   
 (d)  $(\text{CH}_3)_3\text{COK}/(\text{CH}_3)_3\text{COH}$ , then NBS/ $\text{CCl}_4$

- 13.4 Which of the following structures does not contribute to the hybrid for the carbocation formed when 4-chloro-2-pentene ionizes in an  $\text{S}_{\text{N}}1$  reaction?

- (a)  $\text{CH}_3\text{CH}=\text{CHCH}^+\text{CH}_3$  (b)  $\text{CH}_3\text{CH}^+\text{CH}=\text{CHCH}_3$  (c)  $\text{CH}_3\text{CH}^+\text{CH}_2\text{CH}=\text{CH}_2$   
 (d) All of these contribute to the resonance hybrid.

- 13.5 Which of the following resonance structures accounts at least in part for the lack of  $\text{S}_{\text{N}}2$  reactivity of vinyl chloride?

- (a)  $\text{CH}_2=\text{CH}-\ddot{\text{Cl}}:$  (b)  $\text{CH}_2^+-\text{CH}=\ddot{\text{Cl}}:$  (c) Neither (d) Both

## SUMMARY OF REACTIONS BY TYPE

## CHAPTERS 1-13

## I. SUBSTITUTION REACTIONS

| Type                                                                                    | Stereochemical Result          | Favoring Conditions                                                                                                                            |
|-----------------------------------------------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Chapter 6<br>See Section 6.15 for a summary of nucleophiles mentioned in early chapters | inversion                      | 1°, 2°, benzylic (1° or 2°), or allylic (1° or 2°) leaving group (e.g., halide, tosylate, mesylate); strong nucleophile; polar aprotic solvent |
| Chapter 6<br>Radical substitution                                                       | racemization (via carbocation) | 3°, benzylic, or allylic leaving group                                                                                                         |
| Chapter 10<br>Section 13.2                                                              | racemization (via radical)     | 3°, benzylic, or allylic hydrogen; peroxides, heat/light                                                                                       |

## II. ELIMINATION REACTIONS

| Type                                  | Stereochemical/Regiochemical Result                                                                                                                                                                          | Favoring Conditions                                                                                                                                         |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Chapter 7.6<br>Section 7.6            | elimination to form the most substituted alkene (Zaitsev elimination) with small bases<br><br>formation of the less substituted alkene with use of a bulky base (e.g., <i>tert</i> -BuOK/ <i>tert</i> -BuOH) | strong base (e.g., NaOEt/EtOH, KOH/EtOH, <i>tert</i> -BuOK/ <i>tert</i> -BuOH);<br>2° or 3° leaving group (e.g., halide, tosylate, mesylate, etc.);<br>heat |
| Chapter 7.6<br>Sections 6.18 and 7.10 | formation of most substituted alkene; may occur with carbocation rearrangement                                                                                                                               | 3° leaving group; weak base; heat                                                                                                                           |
| Chapter 7.7<br>Section 7.7            | formation of most substituted alkene; may occur with carbocation rearrangement                                                                                                                               | catalytic acid (H <sup>+</sup> , e.g., concd H <sub>2</sub> SO <sub>4</sub> , H <sub>3</sub> PO <sub>4</sub> ); heat                                        |

## III. MECHANISTIC SUMMARY OF ALKENE AND ALKYNE ADDITION REACTIONS

| Reactant | Stereochemical Result                                                                               |                                                                                                     | Regiochemical Result                                                                              |                                                                                                   |
|----------|-----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Alkenes  | syn                                                                                                 | anti                                                                                                | Markovnikov                                                                                       | anti-Markovnikov                                                                                  |
|          | H <sub>2</sub> /Pt, Pd or Ni<br>(Section 7.13)                                                      | * X <sub>2</sub> /CCl <sub>4</sub><br>(Section 8.6)                                                 | * H <sub>2</sub> O, H <sup>+</sup> (hydration)<br>(Section 8.5)                                   | (i) THF:BH <sub>3</sub><br>(ii) OH <sup>-</sup> , H <sub>2</sub> O <sub>2</sub><br>(Section 11.7) |
|          | (i) OsO <sub>4</sub> ,<br>(ii) Na <sub>2</sub> SO <sub>3</sub><br>(Section 8.10)                    | * X <sub>2</sub> , H <sub>2</sub> O<br>(Section 8.8)                                                | * (i) Hg(OAc) <sub>2</sub> ,<br>H <sub>2</sub> O, THF<br>(ii) NaBH <sub>4</sub><br>(Section 11.5) |                                                                                                   |
|          | RCO <sub>3</sub> H (e.g., MMPP)<br>(Section 11.17)                                                  | (i) RCO <sub>3</sub> H,<br>(ii) H <sub>3</sub> O <sup>+</sup> or OH <sup>-</sup><br>(Section 11.18) | * HX (no peroxides)<br>(Section 8.2)                                                              | HBr (w/peroxides)<br>(Section 10.9)                                                               |
|          | * (i) THF:BH <sub>3</sub><br>(ii) H <sub>2</sub> O <sub>2</sub> , OH <sup>-</sup><br>(Section 10.7) | * X <sub>2</sub> /ROH<br>(Section 8.8)                                                              | * addition of other alkenes                                                                       |                                                                                                   |
|          |                                                                                                     | * X <sub>2</sub> , Nucleophile (e.g., RO <sup>-</sup> , RMgX)<br>(Section 8.8)                      |                                                                                                   |                                                                                                   |
|          | :C< Addition of carbenes<br>(Section 8.9)                                                           |                                                                                                     |                                                                                                   |                                                                                                   |

\*Shares mechanistic themes with other reactions denoted by the same symbol.

| Alkynes |                                                                                         |                                                                                                           |                                                     |
|---------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
|         | H <sub>2</sub> , Pd on BaCO <sub>3</sub> w/quinoline Lindlar's cat.)<br>(Section 7.15A) | (i) Li, EtNH <sub>2</sub> , -78°C<br>(ii) NH <sub>4</sub> <sup>+</sup> Cl <sup>-</sup><br>(Section 7.15B) | HX (one or two molar equivalents)<br>(Section 8.13) |
|         | H <sub>2</sub> , Ni <sub>2</sub> B (P-2)<br>(Section 7.15A)                             | X <sub>2</sub> (2 equiv.)/CCl <sub>4</sub><br>(Section 8.12)                                              |                                                     |
|         | H <sub>2</sub> (2 equiv.), Pt or Ni (complete hydrogenation)<br>(Section 7.15)          |                                                                                                           |                                                     |



## IV. ALKENE AND ALKYNE CLEAVAGE WITH OXIDATION

| Conditions                                                                            | Reactant                | Product(s)                              |
|---------------------------------------------------------------------------------------|-------------------------|-----------------------------------------|
| <b>Alkenes</b>                                                                        |                         |                                         |
| (i) $\text{KMnO}_4/\text{OH}^-$ , heat; (ii) $\text{H}_3\text{O}^+$<br>(Section 8.11) | tetrasubstituted alkene | → two ketones                           |
|                                                                                       | trisubstituted alkene   | → one ketone, one carboxylic acid       |
|                                                                                       | monosubstituted alkene  | → one carboxylic acid and $\text{CO}_2$ |
| (i) $\text{O}_3$ , (ii) Zn, HOAc<br>(Section 8.11A)                                   | tetrasubstituted alkene | → two ketones                           |
|                                                                                       | trisubstituted alkene   | → one ketone, one aldehyde              |
|                                                                                       | monosubstituted alkene  | → one aldehyde and formaldehyde         |
| <b>Alkynes</b>                                                                        |                         |                                         |
| (i) $\text{KMnO}_4/\text{OH}^-$ , heat; (ii) $\text{H}_3\text{O}^+$<br>(Section 8.14) | terminal alkyne         | → a carboxylic acid and formic acid     |
|                                                                                       | internal alkyne         | → two carboxylic acids                  |
| (i) $\text{O}_3$ , (ii) Zn, HOAc<br>(Section 8.14)                                    | terminal alkyne         | → a carboxylic acid and formic acid     |
|                                                                                       | internal alkyne         | → two carboxylic acids                  |

## V. CARBON—CARBON BOND-FORMING REACTIONS

- Alkylation of alkynide anions (with  $1^\circ$  alkyl halides, epoxides, and aldehydes or ketones) (Sections 4.18C, 4.20B, 7.12 and 12.8D)
- Grignard reaction (with aldehydes and ketones, or epoxides) (Sections 12.7B, C, and 12.8)
- Reactions of lithium dialkylcuprates (Corey-House, Posner-Whitesides reaction) (Section 12.9)
- Carbocation addition to alkenes (e.g., polymerization) (Special Topic A)
- Diels-Alder reaction (Section 13.11)
- Addition of a carbene to an alkene (Section 8.9)

## VI. REDUCTIONS/OXIDATIONS (NOT INCLUDING ALKENES/ALKYNES)

- $2 \text{R}-\text{X} (\text{w}/\text{Zn}/\text{H}^+) \rightarrow 2 \text{R}-\text{H} + \text{ZnX}_2$  (Section 4.18B)
- Lithium aluminum hydride ( $\text{LiAlH}_4$ ) and sodium borohydride ( $\text{NaBH}_4$ ) reduction of carbonyl compounds (Section 12.3)
- Oxidation of alcohols with chromic acid, pyridinium chlorochromate (PCC), or hot potassium permanganate (Section 12.4)

## VII. MISCELLANEOUS

- $\text{R}-\text{CO}-\text{R} + \text{PCl}_5 \rightarrow \text{R}-\text{CCl}_2-\text{R} \rightarrow$  alkynes (Section 7.10)
- $\text{R}-\text{COOH} + \text{SOCl}_2$  or  $\text{PCl}_5 \rightarrow \text{R}-\text{COCl} \rightarrow$  acyl chlorides for Friedel-Crafts reactions, esters, amides, etc. (Sections 15.7 and 18.5)
- Terminal alkynes +  $\text{NaNH}_2$  in  $\text{NH}_3 \rightarrow$  alkynide anions (Sections 4.18C, 12.8D)
- $\text{R}-\text{OH} + \text{TsCl}$  or  $\text{MsCl}$  (with pyridine)  $\rightarrow \text{R}-\text{OTs}$  or  $\text{R}-\text{OMs}$  (Section 11.10)
- $\text{R}-\text{OH} + \text{Na}$  (or  $\text{NaNH}_2$ )  $\rightarrow \text{R}-\text{O}^-\text{Na}^+ + \text{H}_2$  (or  $\text{NH}_3$ ) (Sections 6.16B, 11.15B)

## VIII. CHEMICAL TESTS

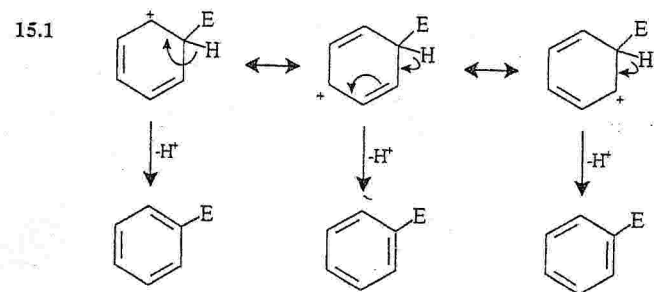
- Alkenes/Alkynes:  $\text{Br}_2/\text{CCl}_4$  (Section 8.6)
- Rings/Unsaturation/etc.: Index of Hydrogen Deficiency (Section 7.16)
- Position of Unsaturation:  $\text{KMnO}_4$  (Section 8.11);  $\text{O}_3$  (Section 8.11A)



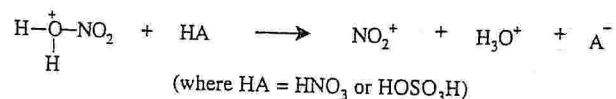
# 15

## REACTIONS OF AROMATIC COMPOUNDS

### SOLUTIONS TO PROBLEMS



- 15.2 The rate is dependent on the concentration of  $\text{NO}_2^+$  ion formed from protonated nitric acid.

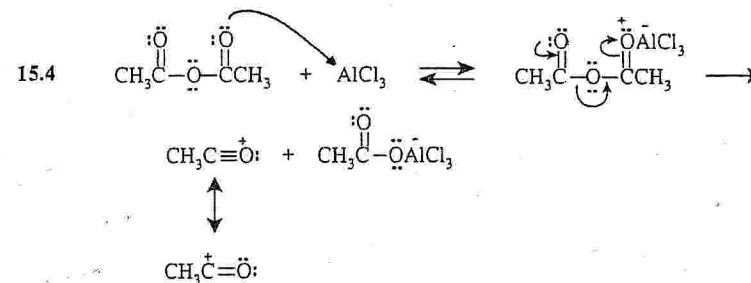
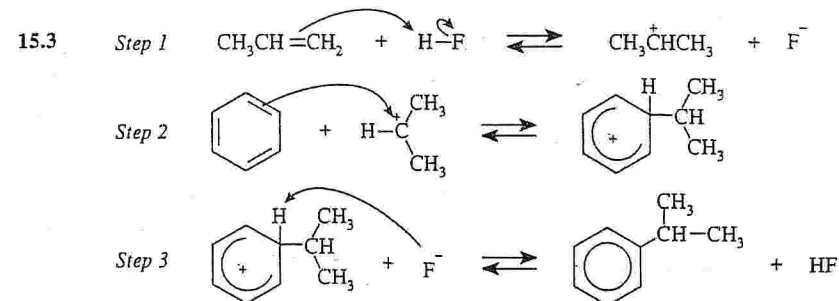
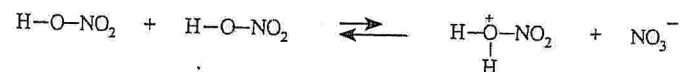


Because  $\text{H}_2\text{SO}_4$  ( $\text{HOSO}_3\text{H}$ ) is a stronger acid, a mixture of it and  $\text{HNO}_3$  will contain a higher concentration of protonated nitric acid than will nitric acid alone.

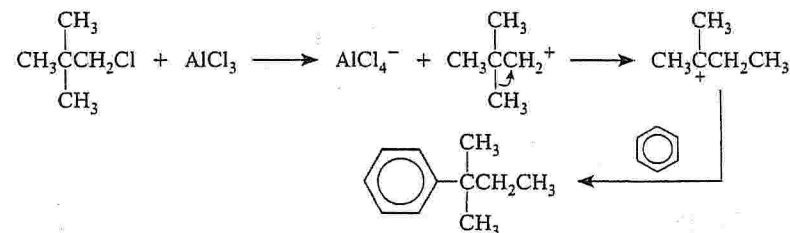
That is, the reaction,



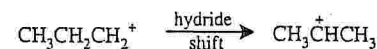
produces more protonated nitric acid than the reaction,



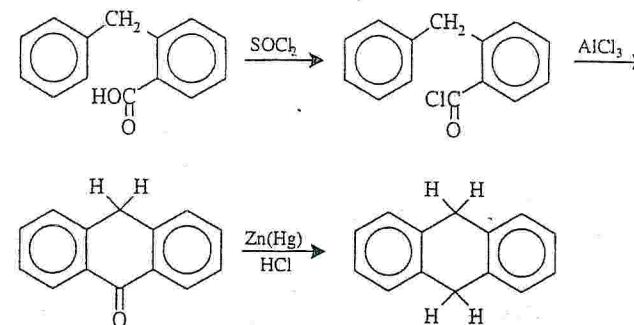
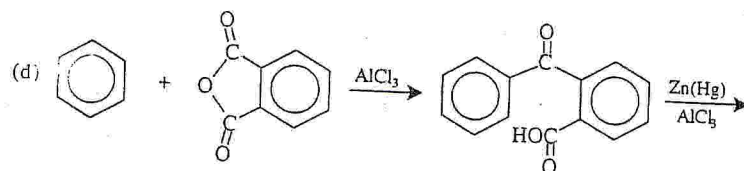
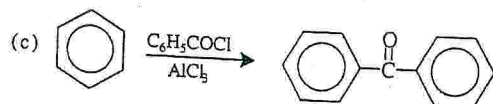
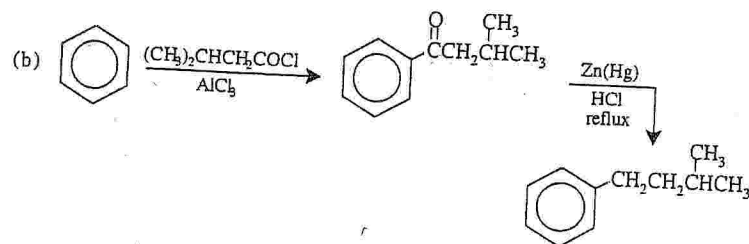
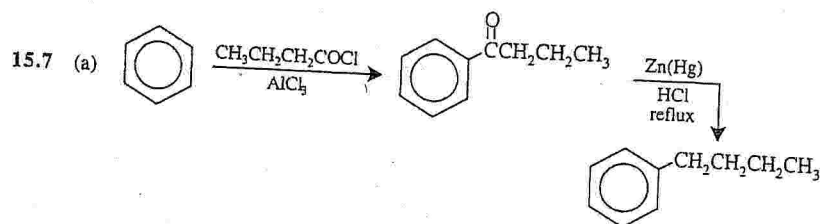
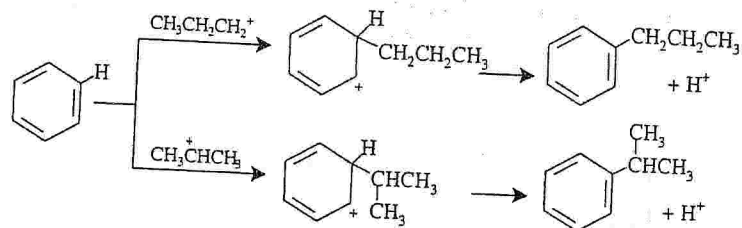
- 15.5 The carbocation formed by the action of  $\text{AlCl}_3$  on neopentyl chloride is primary. This carbocation rearranges to the more stable tertiary carbocation before it can react with the benzene ring:



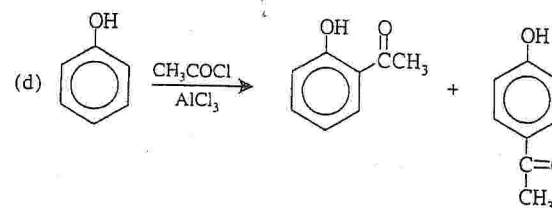
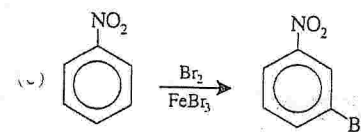
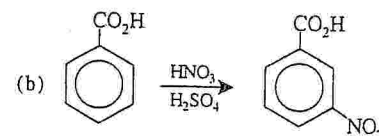
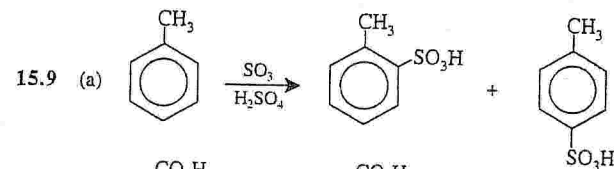
- 15.6  $\text{CH}_3\text{CH}_2\text{CH}_2-\text{OH} + \text{BF}_3 \rightleftharpoons \text{CH}_3\text{CH}_2\text{CH}_2^+ + \text{HOBF}_3$   
The propyl cation can rearrange into an isopropyl cation:



Both carbocations can then attack the ring.

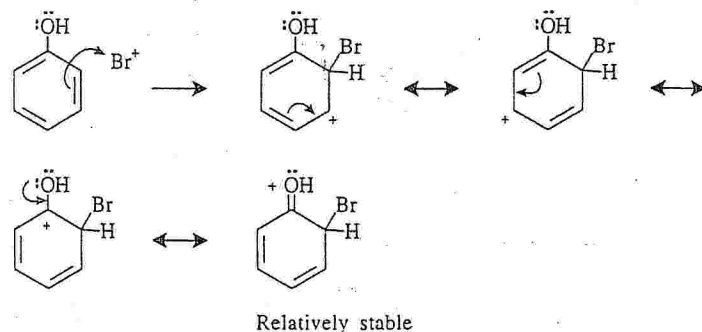


15.8 If the methyl group had no directive effect on the incoming electrophile, we would expect to obtain the products in purely statistical amounts. Since there are two ortho hydrogen atoms, two meta hydrogen atoms, and one para hydrogen, we would expect to get 40% ortho (2/5), 40% meta (2/5), and 20% para (1/5). Thus, we would expect that only 60% of the mixture of mononitrotoluenes would have the nitro group in the ortho or para position. And we would expect to obtain 40% of *m*-nitrotoluene. In actuality, we get 96% of combined *o*- and *p*-nitrotoluene and only 4% *m*-nitrotoluene. This shows the ortho-para directive effect of the methyl group.

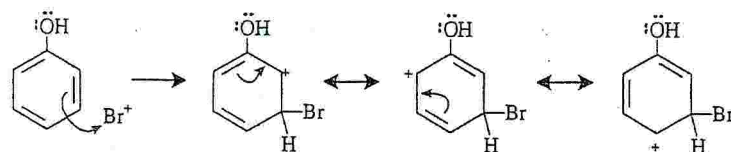


- 15.10 As the following structures show, attack at the ortho and para positions of phenol leads to arenium ions that are more stable (than the one resulting from meta attack) because they are hybrids of four resonance structures, one of which is relatively stable. Only three resonance structures are possible for the meta arenium ion, and none is relatively stable.

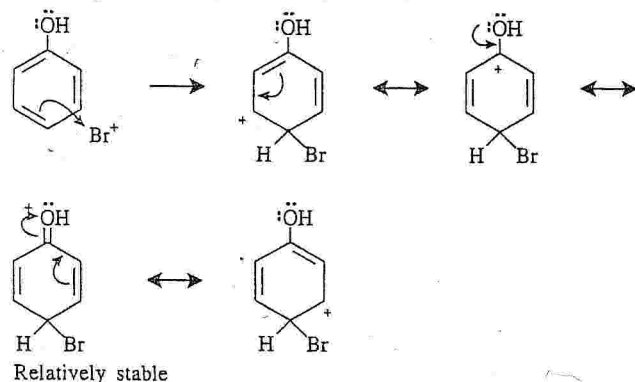
*Ortho attack*



*Meta attack*

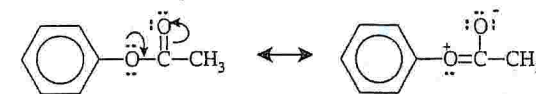


*Para attack*



- 15.11 (a) The atom (an oxygen atom) attached to the benzene ring has an unshared electron pair that it can donate to the arenium ions formed from ortho and para attack stabilizing them. (The arenium ions are analogous to the previous answer with a  $-\text{COCH}_3$  group replacing the  $-\text{H}$ ).

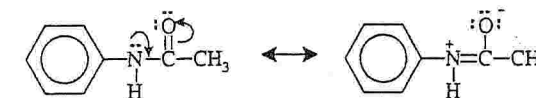
(b) Structures such as the following compete with the benzene ring for the oxygen electrons, making them less available to the benzene ring.



This effect makes the benzene ring of phenyl acetate less electron rich and, therefore, less reactive.

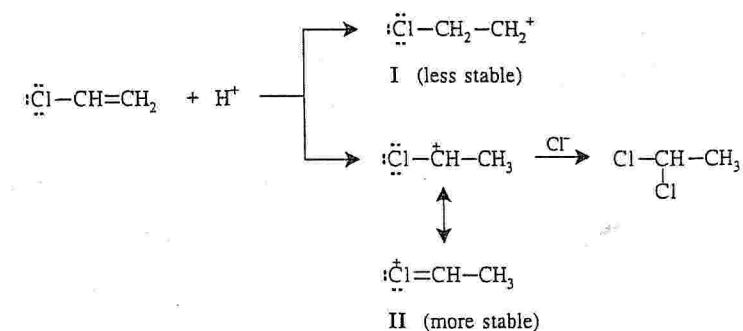
(c) Because the acetamido group has an unshared electron pair on the nitrogen atom that it can donate to the benzene ring it is an ortho-para director.

(d) Structures such as the following compete with the benzene ring for the nitrogen electrons, making them less available to the benzene ring.

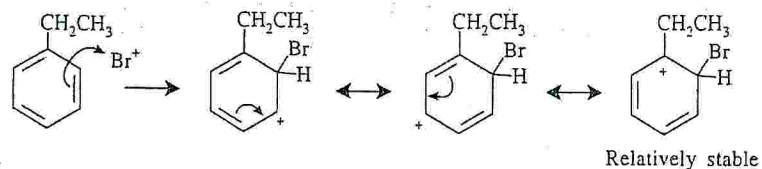
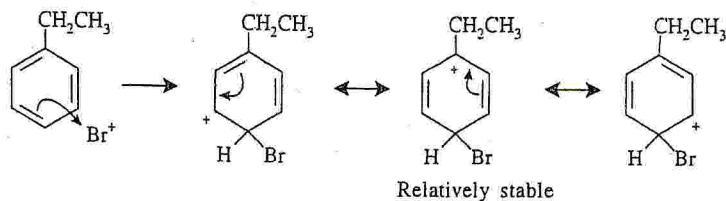


- 15.12 The electron-withdrawing inductive effect of the chlorine of chloroethene makes its double bond less electron rich than that of ethene. This causes the rate of reaction of chloroethene with an electrophile (i.e., a proton) to be slower than the corresponding reaction of ethene.

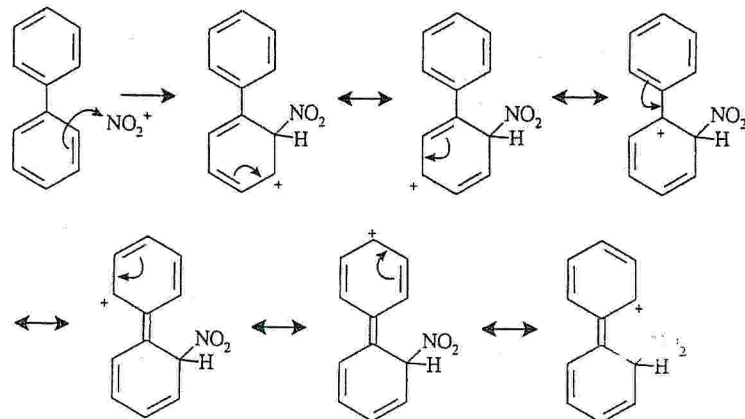
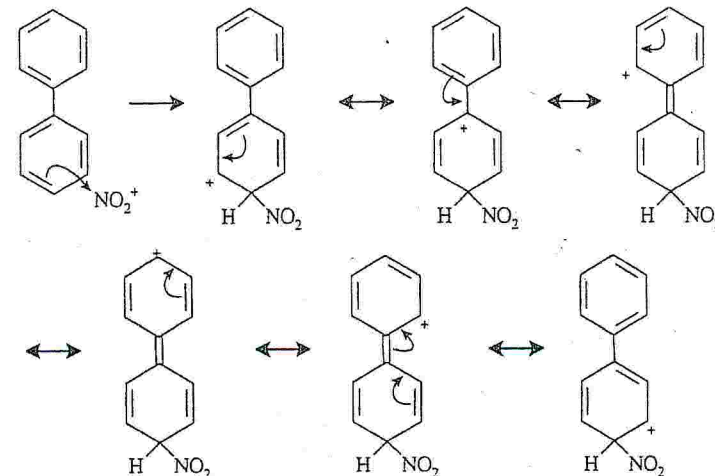
When chloroethene adds a proton, the orientation is governed by a resonance effect. In theory, two carbocations can form:



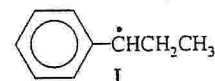
Carbocation II is more stable than I because of the resonance contribution of the extra structure just shown in which the chlorine atom donates an electron pair (see Section 15.11D).

15.13 *Ortho attack**Para attack*

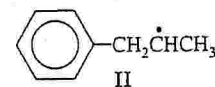
- 15.14 The phenyl group, as the following resonance structures show, can act as an electron-releasing group and can stabilize the arenium ions formed from ortho and para attack.

*Ortho attack**Para attack*

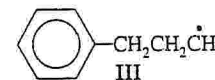
## 15.15



leads to 1-chloro-1-phenylpropane

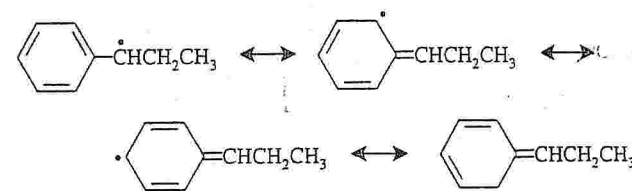


leads to 2-chloro-1-phenylpropane

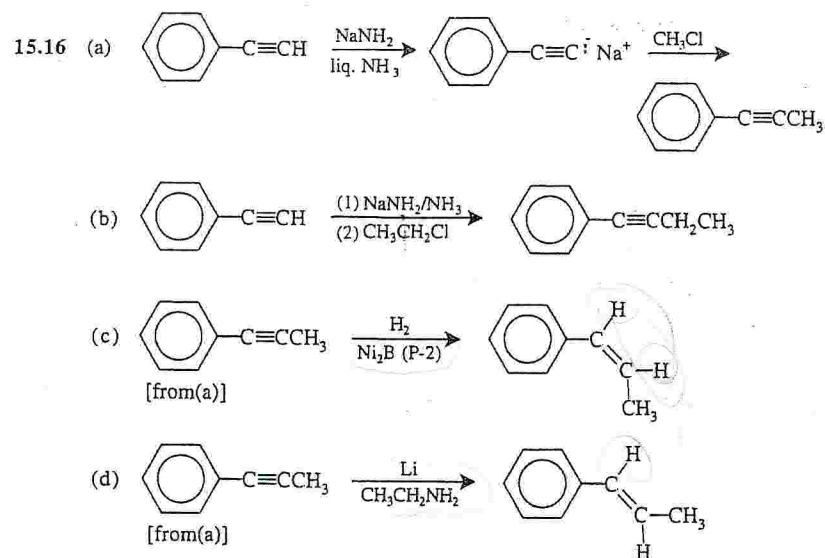


leads to 1-chloro-3-phenylpropane

The major product is 1-chloro-1-phenylpropane because I is the most stable radical. It is a benzylic radical and therefore is stabilized by resonance.



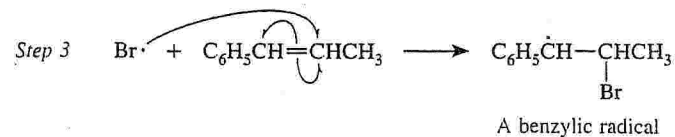
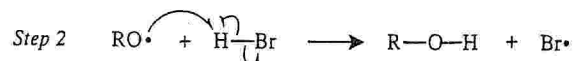
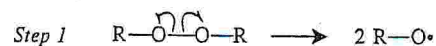




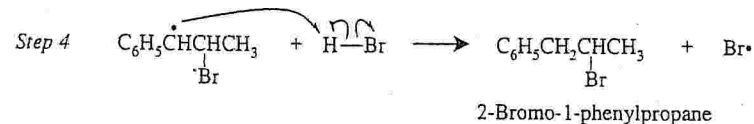
15.17 The addition of hydrogen bromide to 1-phenylpropene proceeds through a benzylic radical in the presence of peroxides, and through a benzylic cation in their absence (cf., a and b as follows).

(a) Hydrogen bromide addition in the presence of peroxides.

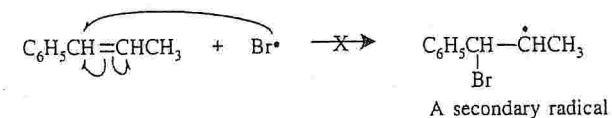
*Chain Initiation*



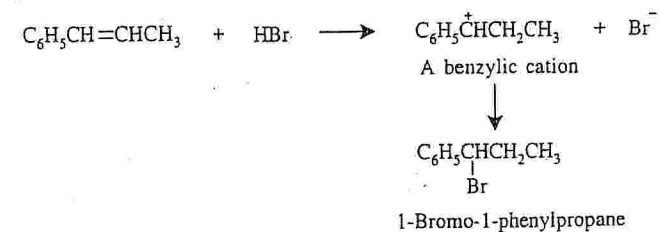
*Chain Propagation*



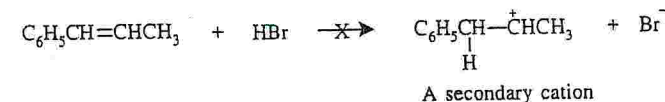
The mechanism for the addition of hydrogen bromide to 1-phenylpropene in the presence of peroxides is a chain mechanism analogous to the one we discussed when we described anti-Markovnikov addition in Section 10.9. The step that determines the orientation of the reaction is the first chain-propagating step. Bromine attacks the second carbon atom of the chain because by doing so the reaction produces a more stable benzylic radical. Had the bromine atom attacked the double bond in the opposite way, a less stable secondary radical would have been formed.

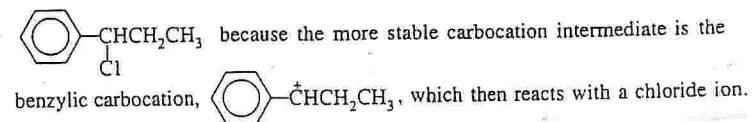


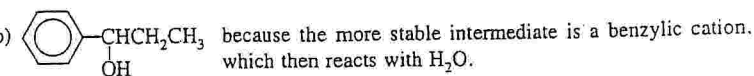
(b) Hydrogen bromide addition in the absence of peroxides.



In the absence of peroxides, hydrogen bromide adds through an ionic mechanism. The step that determines the orientation in the ionic mechanism is the first, where the proton attacks the double bond to give the more stable benzylic cation. Had the proton attacked the double bond in the opposite way, a less stable secondary cation would have been formed.



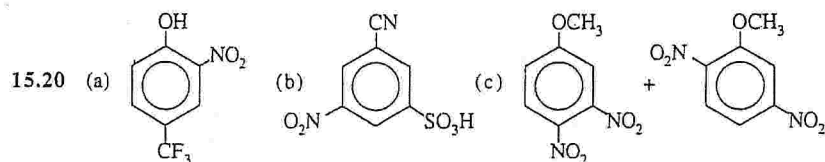
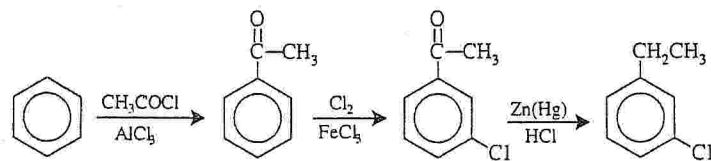
15.18 (a)  because the more stable carbocation intermediate is the benzylic carbocation,  $\text{C}_6\text{H}_5\text{CH}^+\text{CH}_2\text{CH}_3$ , which then reacts with a chloride ion.

(b)  because the more stable intermediate is a benzylic cation, which then reacts with  $\text{H}_2\text{O}$ .

- 15.19 (a) The first method would fail because introducing the chlorine substituent first would introduce an ortho-para directing group. Consequently, the subsequent Friedel-Crafts reaction would not then take place at the desired meta position.

The second method would fail for essentially the same reasons. Introducing the ethyl group first would introduce an ortho-para director, and subsequent ring chlorination would not take place at the desired meta position.

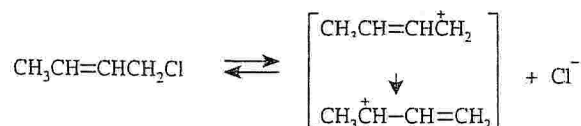
(b) If we introduce an acetyl group first, which we later convert to an ethyl group, we install a meta director. This allows us to put the chlorine atom in the desired position. Conversion of the acetyl group to an ethyl group is then carried out using the Clemmensen reduction.



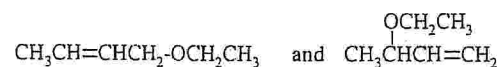
- 15.21 (a) In concentrated base and ethanol (a relatively nonpolar solvent), the  $S_N2$  reaction is favored. Thus, the rate depends on the concentration of both the alkyl halide and  $\text{NaOC}_2\text{H}_5$ . Since no carbocation is formed, the only product is



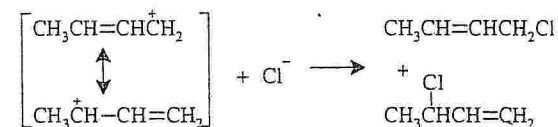
(b) When the concentration of  $\text{C}_2\text{H}_5\text{O}^-$  ion is small or zero, the reaction occurs through the  $S_N1$  mechanism. The carbocation that is produced in the first step of the  $S_N1$  mechanism is a resonance hybrid.



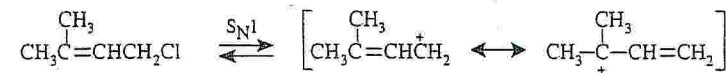
This ion reacts with the nucleophile ( $\text{C}_2\text{H}_5\text{O}^-$  or  $\text{C}_2\text{H}_5\text{OH}$ ) to produce two isomeric ethers



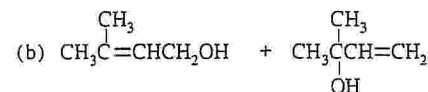
- (c) In the presence of water, the first step of the  $S_N1$  reaction occurs. The reverse of this reaction produces two compounds because the positive charge on the carbocation is distributed over carbon atoms one and three



- 15.22 (a) The carbocation that is produced in the  $S_N1$  reaction is exceptionally stable because one resonance contributor is not only allylic but also tertiary.



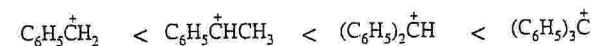
A 3° allylic carbocation



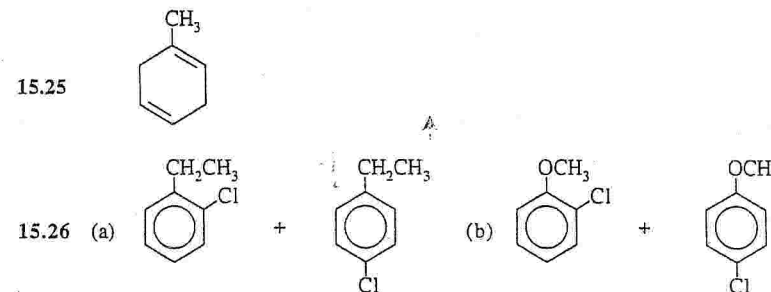
- 15.23 Compounds that undergo reactions by an  $S_N1$  path must be capable of forming relatively stable carbocations. Primary halides of the type  $\text{ROCH}_2\text{X}$  form carbocations that are stabilized by resonance:

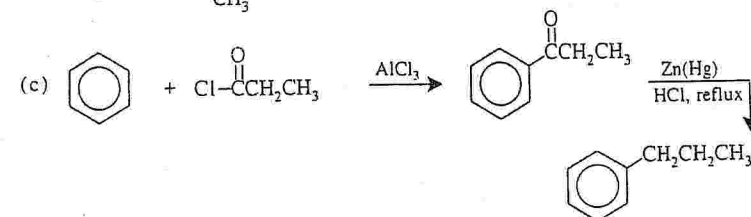
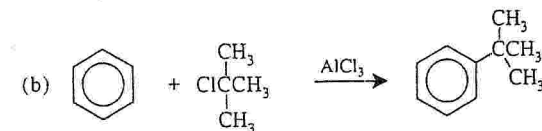
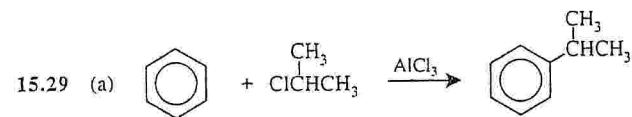
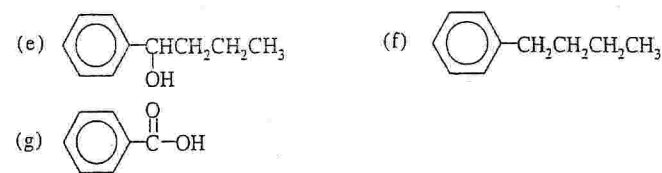
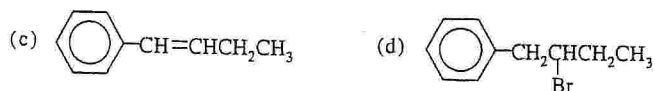
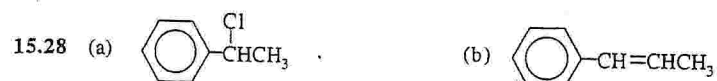
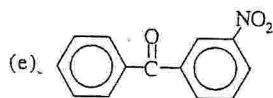
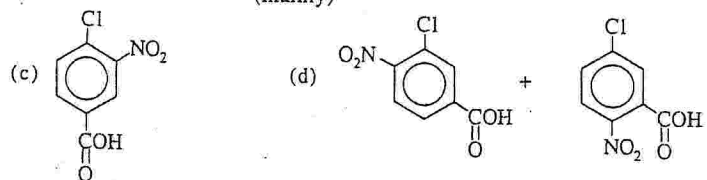
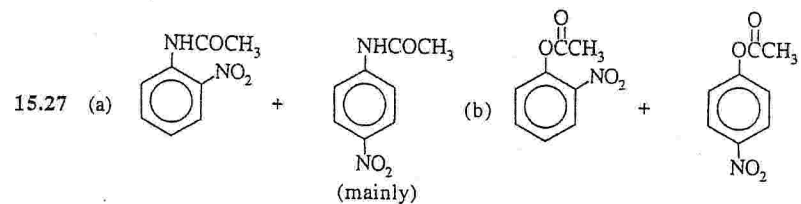
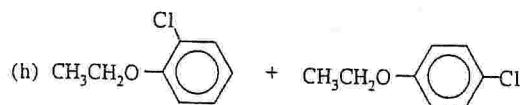
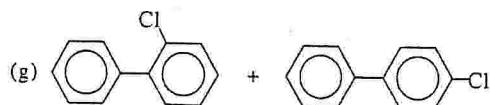
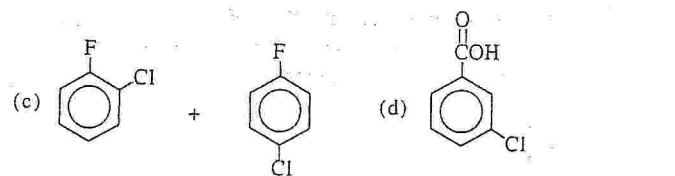


- 15.24 The relative rates are in the order of the relative stabilities of the carbocations:

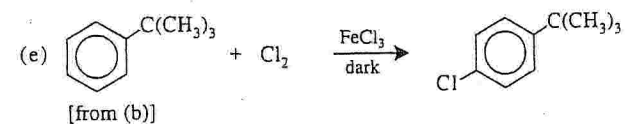
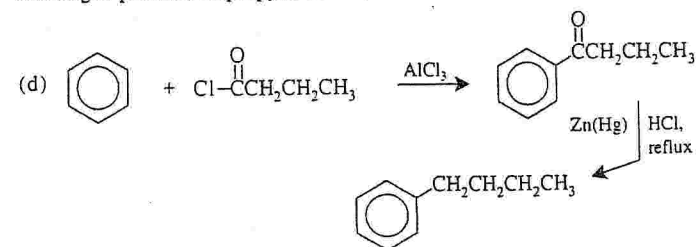


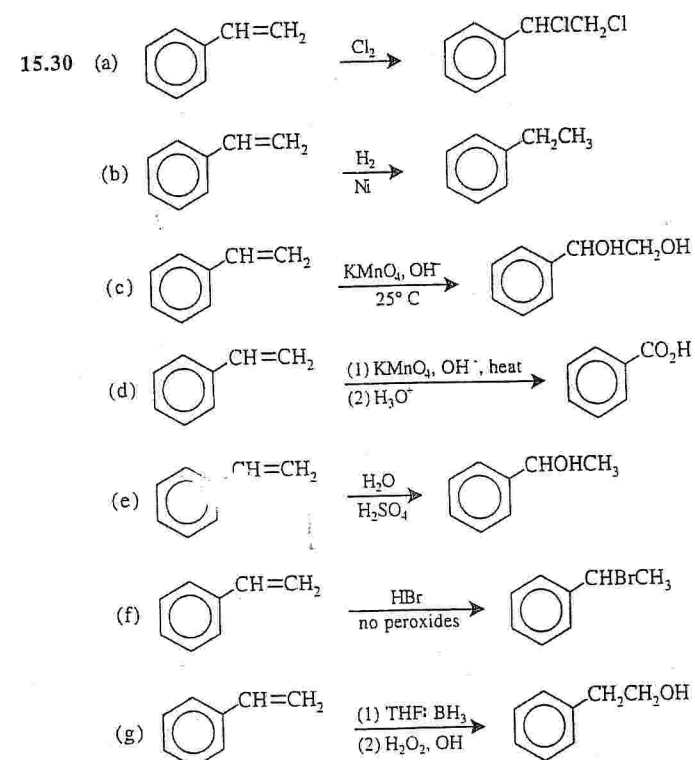
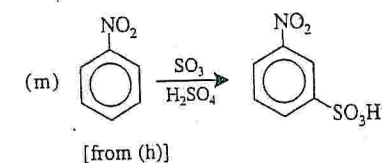
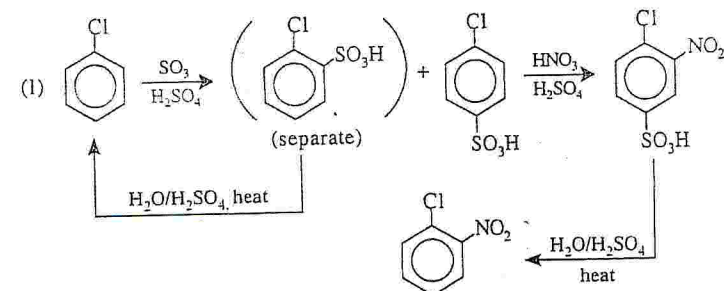
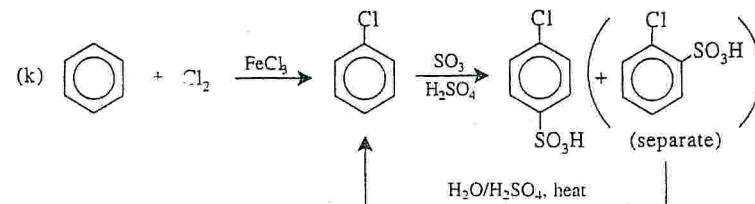
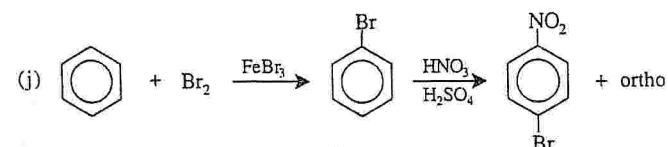
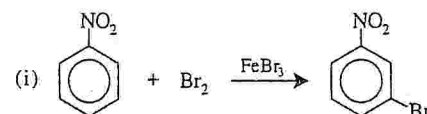
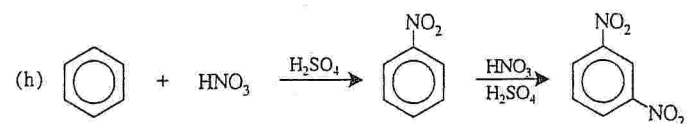
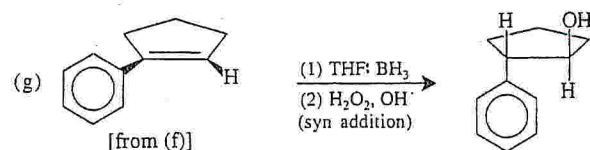
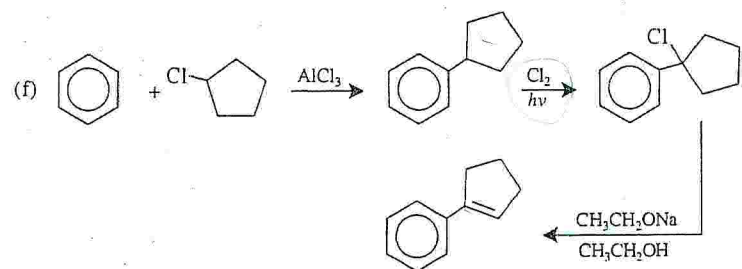
The solvolysis reaction involves a carbocation intermediate.



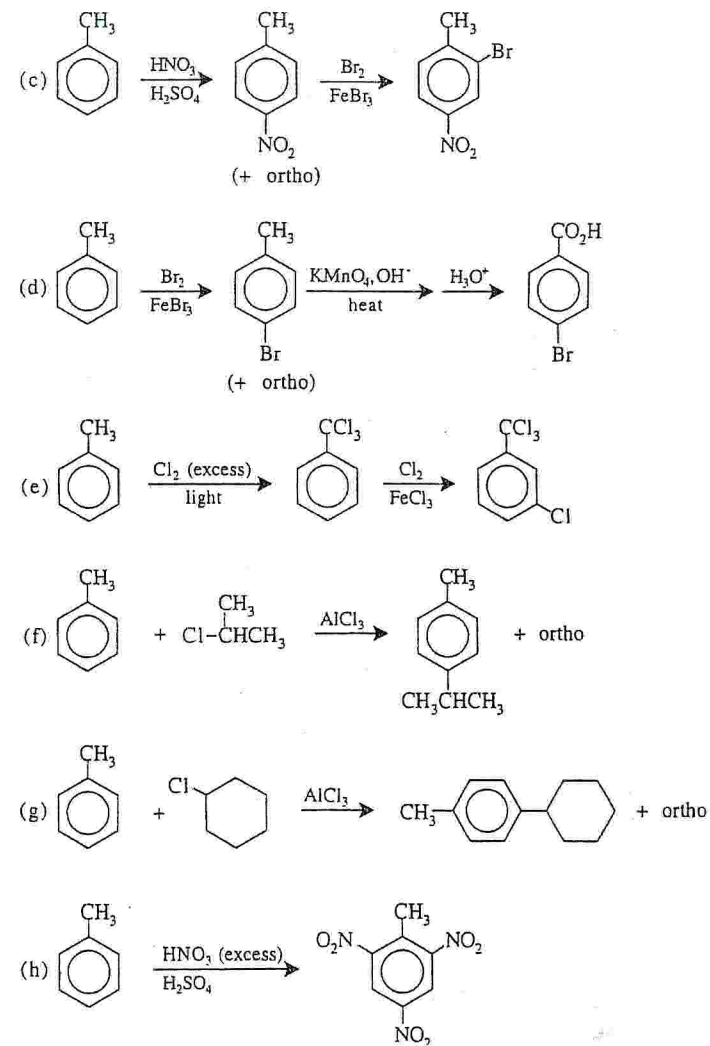
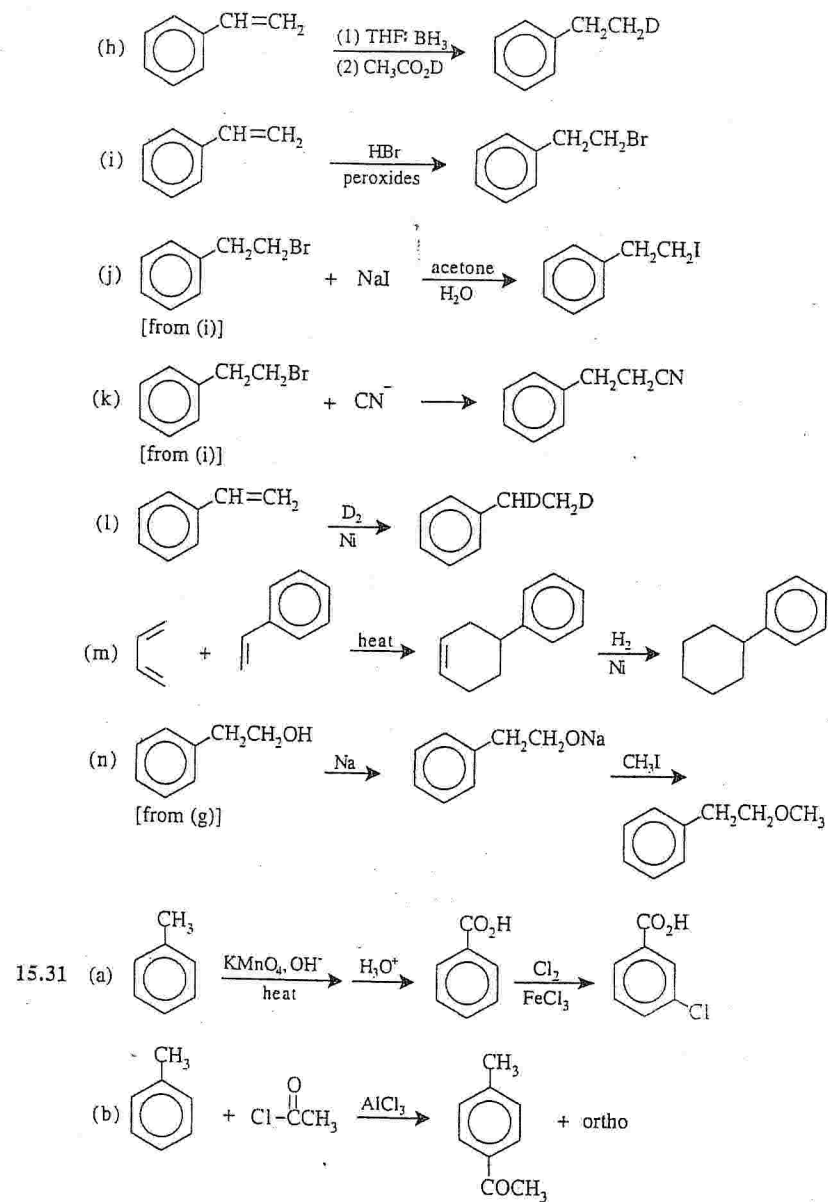


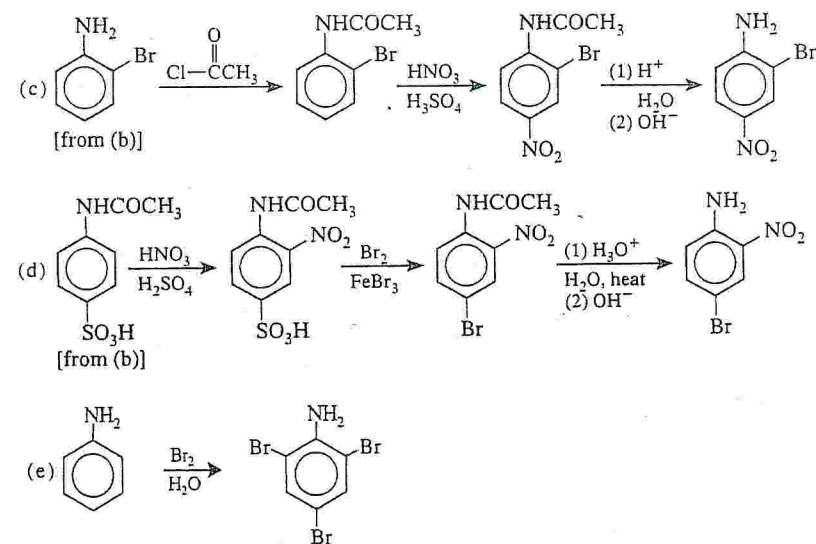
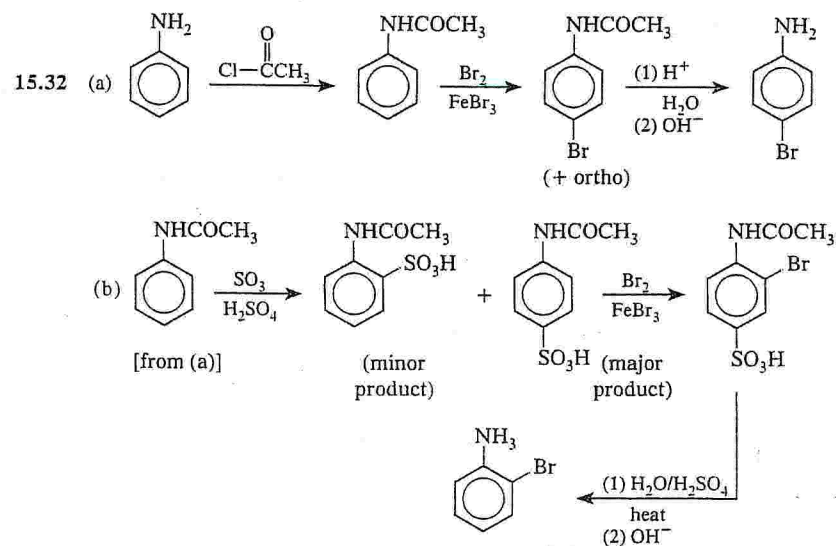
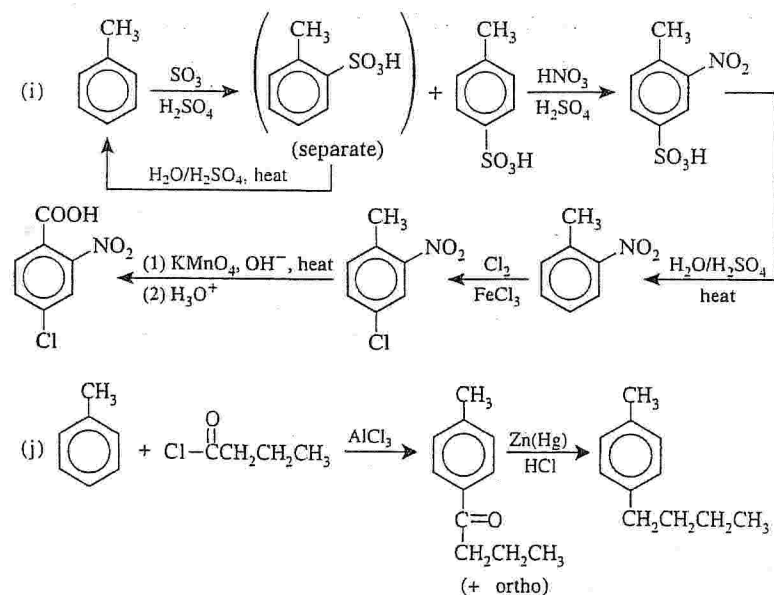
(Note: The use of  $\text{Cl-CH}_2\text{CH}_2\text{CH}_3$  in a Friedel-Crafts synthesis gives mainly the rearranged product, isopropylbenzene.)



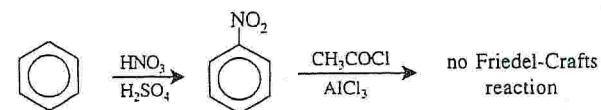




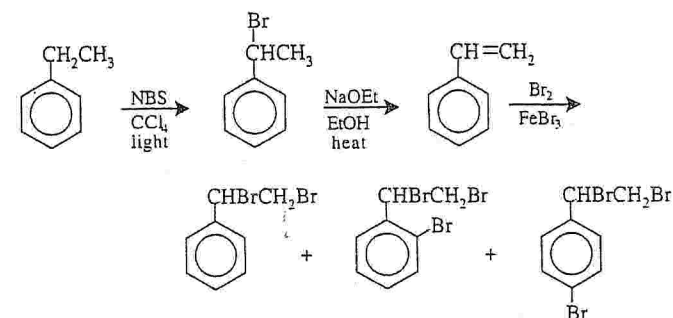


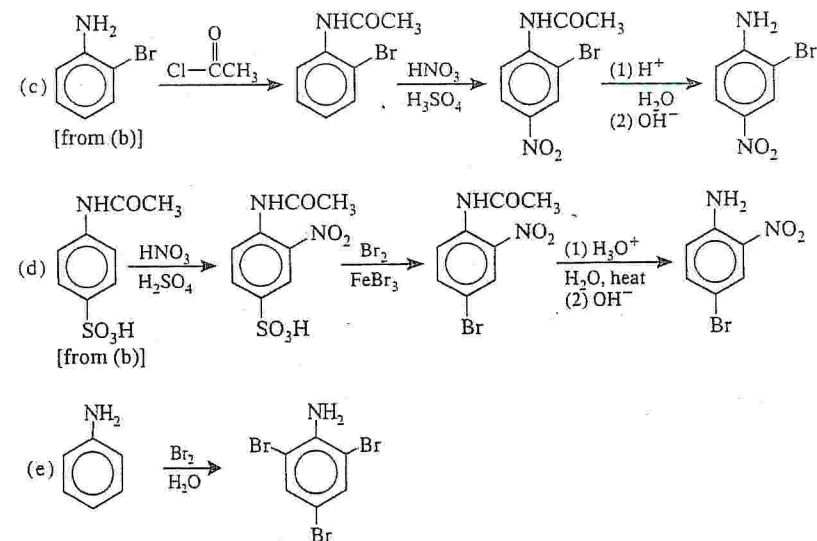
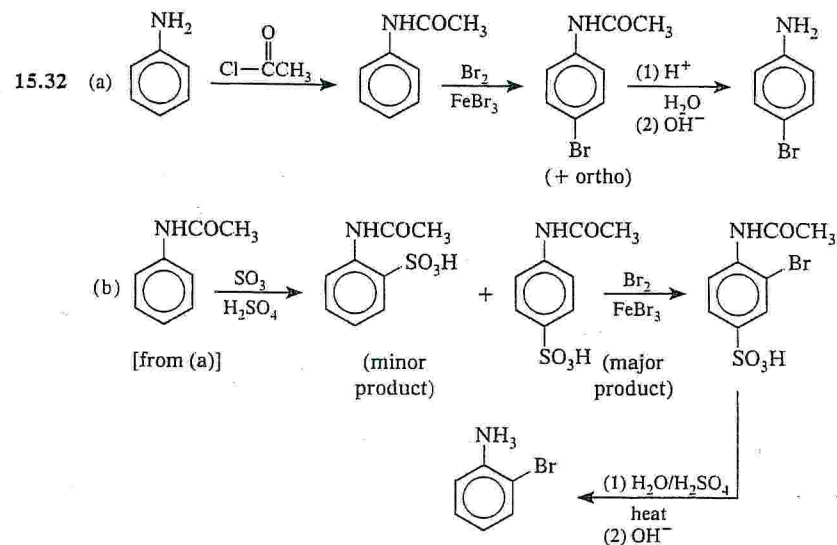
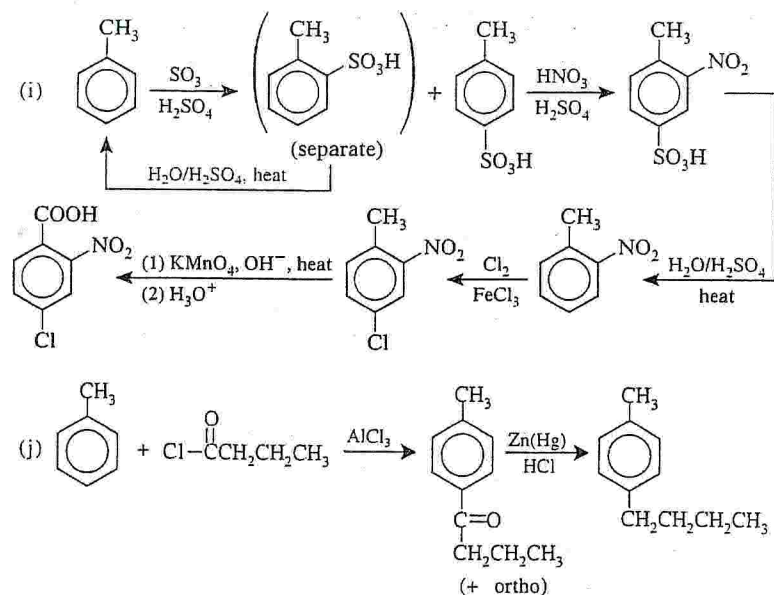


15.33 (a) Step (2) will fail because a Friedel-Crafts reaction will not take place on a ring that bears an  $-\text{NO}_2$  group (or any meta director).

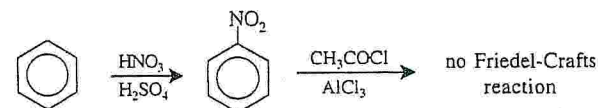


(b) The last step will first brominate the double bond.

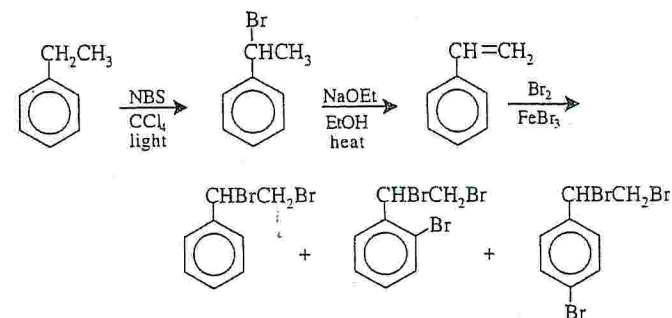




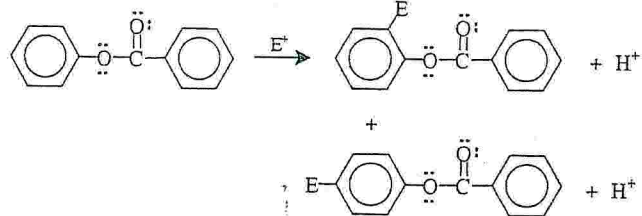
15.33 (a) Step (2) will fail because a Friedel-Crafts reaction will not take place on a ring that bears an  $-\text{NO}_2$  group (or any meta director).



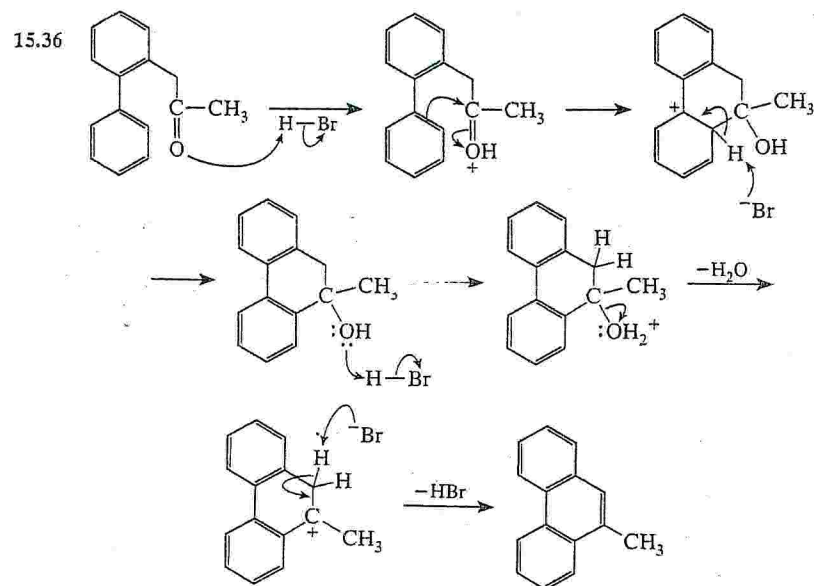
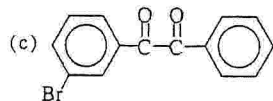
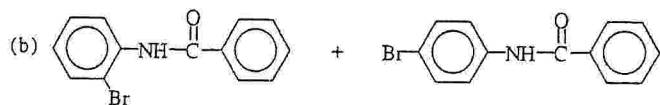
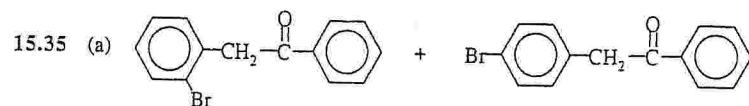
(b) The last step will first brominate the double bond.



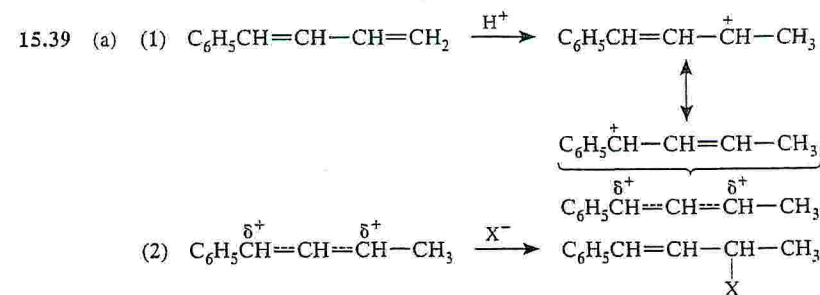
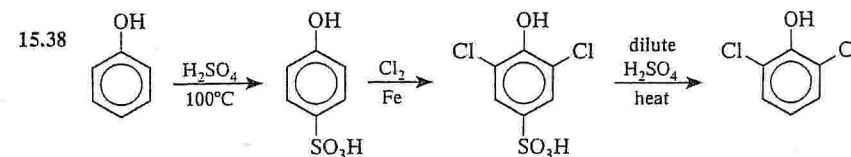
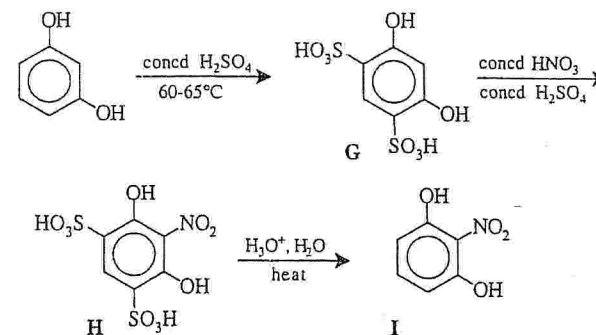
15.34 (a) Electrophilic aromatic substitution will take place as follows:



(b) The ring directly attached to the oxygen atom is activated toward electrophilic attack because the oxygen atom can donate an unshared electron pair to it and stabilize the intermediate arenium ion when attack occurs at the ortho or para position.

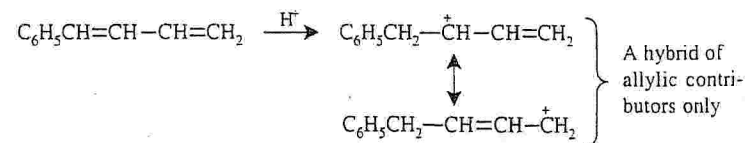


15.37 This problem serves as another illustration of the use of a sulfonic acid group as a blocking group in a synthetic sequence. Here we are able to bring about nitration between two meta substituents.



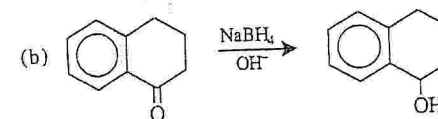
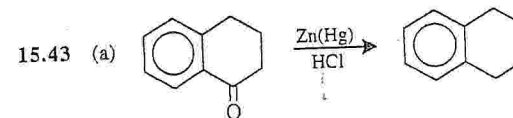
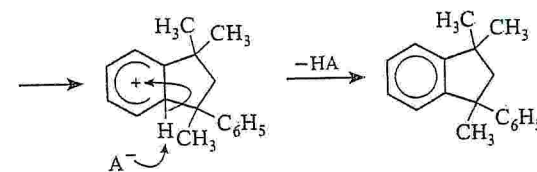
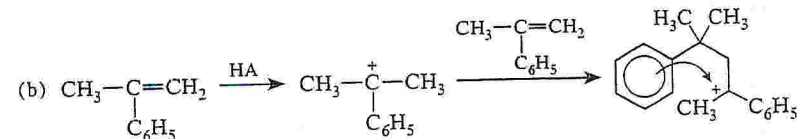
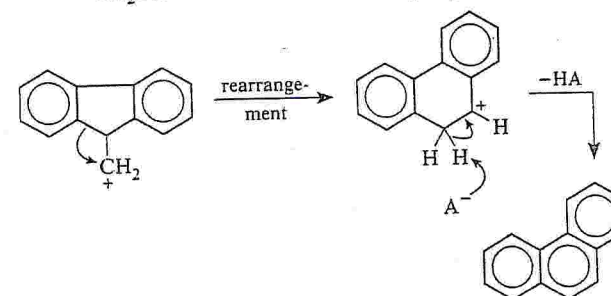
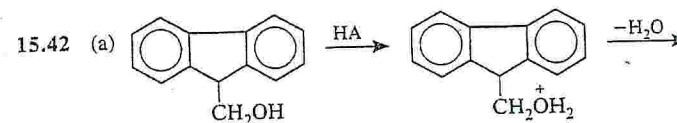
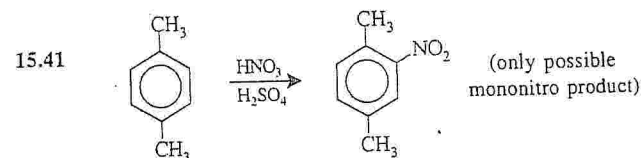
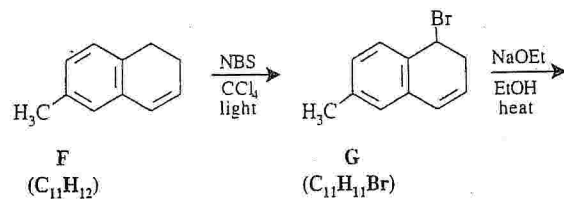
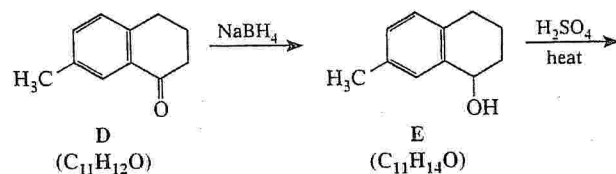
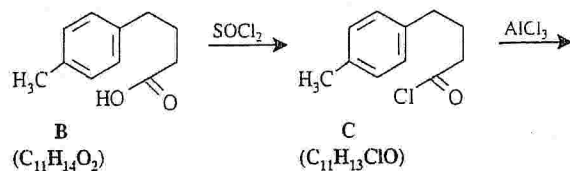
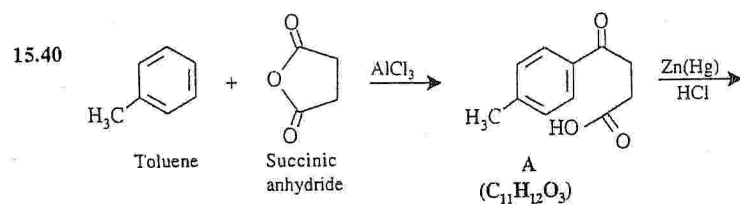
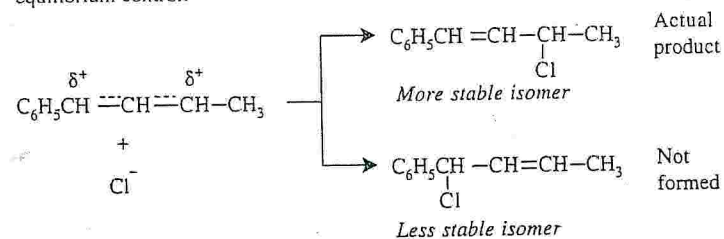
(b) 1,2 Addition.

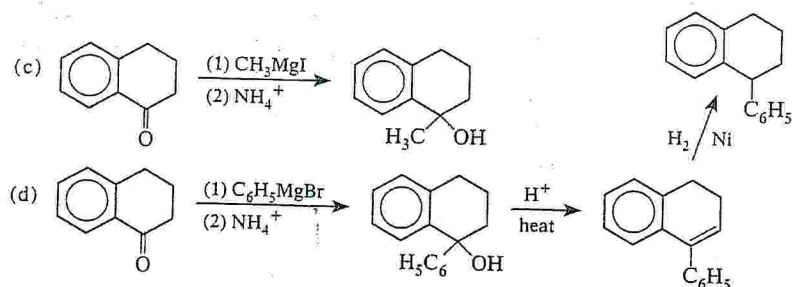
(c) Yes. The carbocation given is a hybrid of *secondary allylic* and *benzylic* contributors and is therefore more stable than any other possibility; for example,



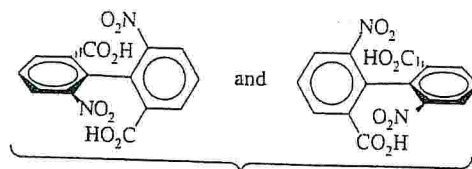


(d) Since the reaction produces only *the more stable isomer*—that is, the one in which the double bond is conjugated with the benzene ring—the reaction is likely to be under equilibrium control:



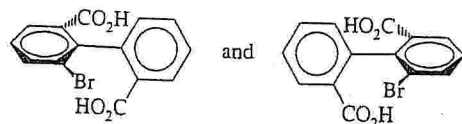


- 15.44 (a) Large ortho substituents prevent the two rings from becoming coplanar and prevent rotation about the single bond that connects them. If the correct substitution patterns are present, the molecule as a whole will be chiral. Thus, enantiomeric forms are possible even though the molecules do not have a stereocenter. The compound with 2-NO<sub>2</sub>, 6-CO<sub>2</sub>H, 2'-NO<sub>2</sub>, 6'-CO<sub>2</sub>H is an example,

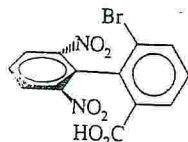


These molecules are nonsuperposable mirror images and, thus, are enantiomers.

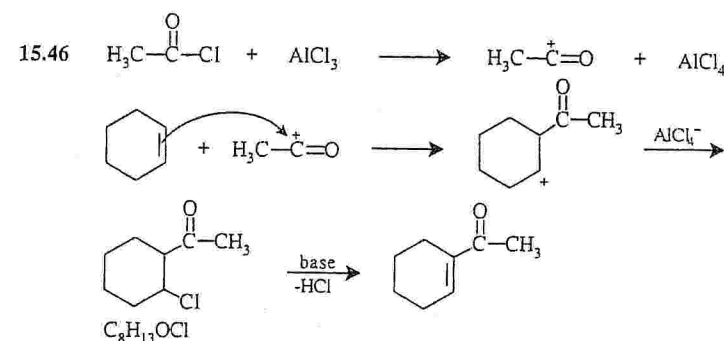
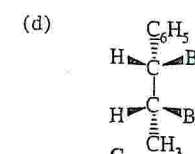
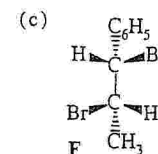
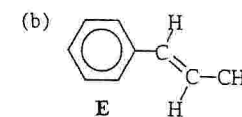
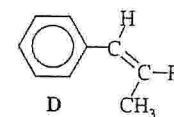
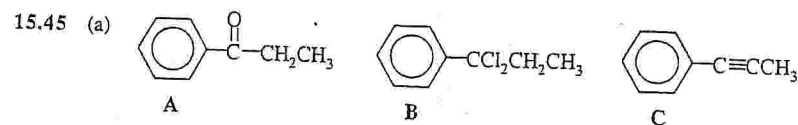
- (b) Yes



- (c) This molecule has a plane of symmetry.



The plane of the page is a plane of symmetry.



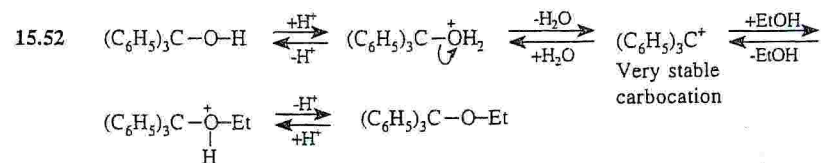
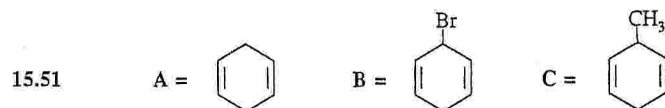
- 15.47 (a and b) The *tert*-butyl group is easily introduced by any of the variations of the Friedel-Crafts alkylation reaction, and, because of the stability of the *tert*-butyl cation, it is easily removed under acidic conditions.

(c) In contrast to the -SO<sub>3</sub>H group often used as a blocking group, -C(CH<sub>3</sub>)<sub>3</sub> activates the ring to further electrophilic substitution.

- 15.48 At the lower temperature, the reaction is kinetically controlled, and the usual o/p directive effects of the -CH<sub>3</sub> group are observed. At higher temperatures, the reaction is thermodynamically controlled. At reaction times long enough for equilibrium to be reached, the most stable isomer, *m*-toluenesulfonic acid, is the principal product.

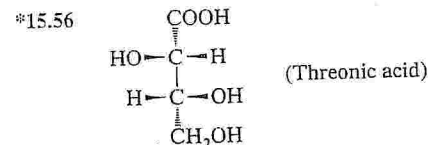
- 15.49 The evidence indicates that the mechanistic step in which the C-H bond is broken is *not* rate determining. (In the case cited, it makes no difference kinetically if a C-H or C-D bond is broken in electrophilic aromatic substitution.) This evidence is consistent with the two-step mechanism given in Section 15.2. The step in which the aromatic compound reacts with the electrophile (NO<sub>2</sub><sup>+</sup>) is the slow rate-determining step. Proton (or deuterium) loss from the arenium ion to return to an aromatic system is a rapid step and has no effect on the overall rate.

- 15.50 (a)  $\text{C}_6\text{H}_5\text{CH}_2\text{Br} \xrightarrow[\text{(-NaBr)}]{\text{NaCN, DMF}} \text{C}_6\text{H}_5\text{CH}_2\text{CN}$
- (b)  $\text{C}_6\text{H}_5\text{CH}_2\text{Br} \xrightarrow[\text{(-NaBr)}]{\text{CH}_3\text{ONa, CH}_3\text{OH}} \text{C}_6\text{H}_5\text{CH}_2\text{OCH}_3$
- (c)  $\text{C}_6\text{H}_5\text{CH}_2\text{Br} \xrightarrow[\text{(-NaBr)}]{\text{CH}_3\text{CO}_2\text{Na, CH}_3\text{CO}_2\text{H}} \text{C}_6\text{H}_5\text{CH}_2\text{O}_2\text{CCH}_3$
- (d)  $\text{C}_6\text{H}_5\text{CH}_2\text{Br} \xrightarrow[\text{(-NaBr)}]{\text{NaI, acetone}} \text{C}_6\text{H}_5\text{CH}_2\text{I}$
- (e)  $\text{CH}_2=\text{CHCH}_2\text{Br} \xrightarrow[\text{(-NaBr)}]{\text{NaN}_3, \text{acetone}} \text{CH}_2=\text{CHCH}_2\text{N}_3$
- (f)  $\text{CH}_2=\text{CHCH}_2\text{Br} \xrightarrow[\text{(-NaBr)}]{\text{NaOCH}_2\text{CH}(\text{CH}_3)_2, (\text{CH}_3)_2\text{CHCH}_2\text{OH}} \text{CH}_2=\text{CHCH}_2\text{OCH}_2\text{CH}(\text{CH}_3)_2$



- 15.53 (a)  $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_2\text{Br}$  would be the most reactive in an  $\text{S}_{\text{N}}2$  reaction because it is a  $1^\circ$  allylic halide. There would, therefore, be less steric hindrance to the attacking nucleophile.
- (b)  $\text{CH}_2=\text{CHCBr}(\text{CH}_3)_2$  would be the most reactive in an  $\text{S}_{\text{N}}1$  reaction because it is a  $3^\circ$  allylic halide. The carbocation formed in the rate-determining step, being both  $3^\circ$  and allylic, would be the most stable.
- 15.54 The final product is *o*-nitroaniline. (The reactions are in Section 15.14.) The presence of six signals in the  $^{13}\text{C}$  NMR spectrum confirms that the substitution in the final product is *ortho* and not *para*. A final product with *para* substitution (i.e., *p*-nitroaniline) would have given only four signals in the  $^{13}\text{C}$  NMR spectrum.

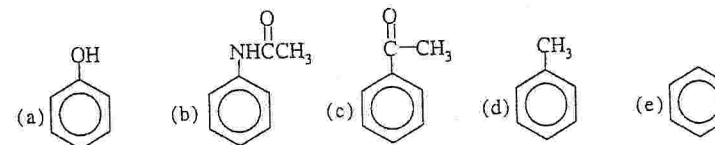
\*15.55  $\text{CH}_2\text{OHCHOHCH}_2\text{OH}$  (Glycerol) After sodium borohydride reduction of the aldehyde, ozonolysis oxidatively degrades the aromatic ring, leaving only the polyhydroxy side chain. Water is an alternative to HOAc sometimes used to work up ozonolysis reactions.



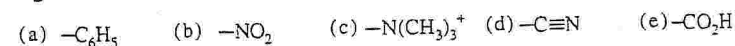
Ozonolysis oxidatively degrades the aromatic rings, leaving only the carboxyl carbon as a remnant of the alkyl substituted benzene ring. Water is an alternative to HOAc used to work up the ozonolysis reaction.

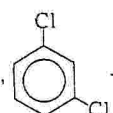
## QUIZ

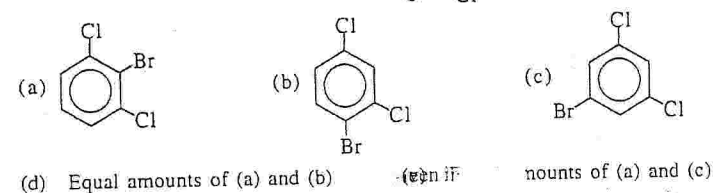
- 15.1 Which of the following compounds would be most reactive toward ring bromination?



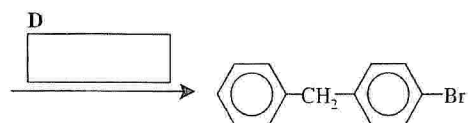
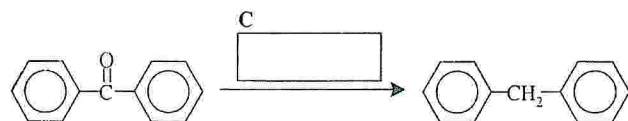
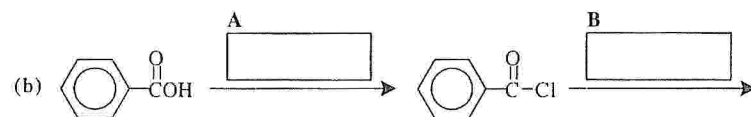
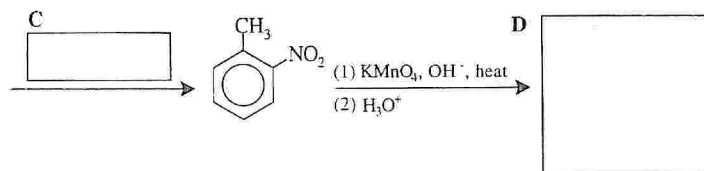
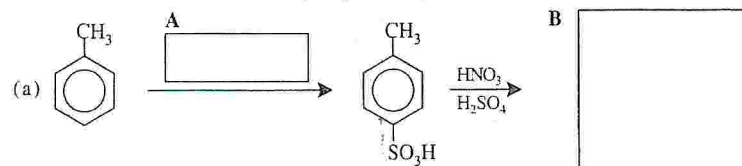
- 15.2 Which of the following is *not* a meta directing substituent when present on a benzene ring?



- 15.3 The major product(s), C, of the reaction,   $\xrightarrow[\text{FeBr}_3]{\text{Br}_2}$  C, would be



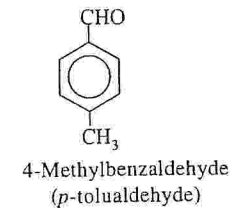
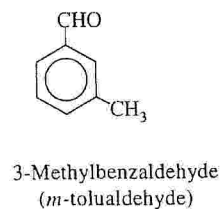
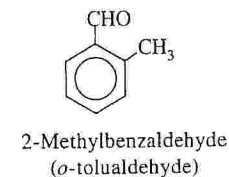
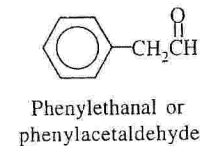
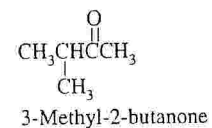
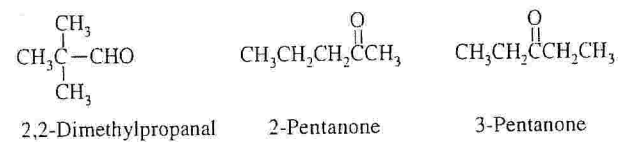
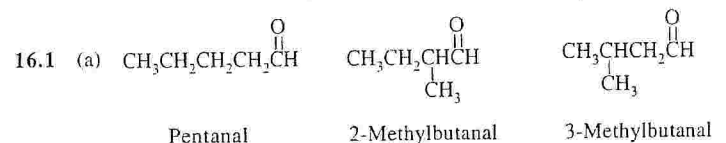
15.4 Complete the following syntheses.



## 16

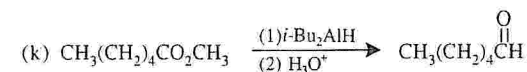
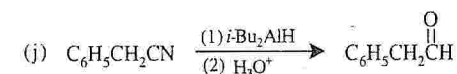
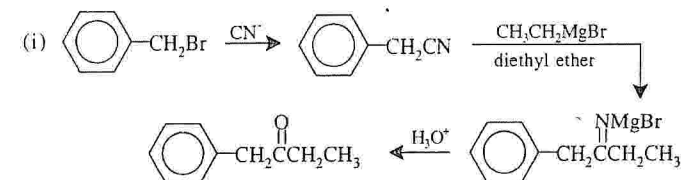
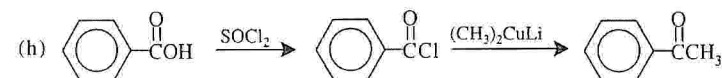
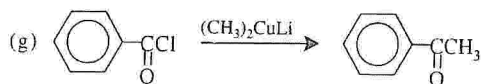
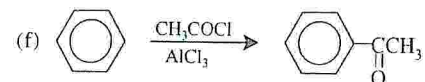
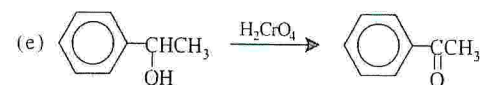
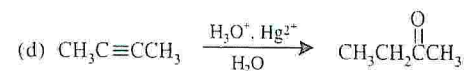
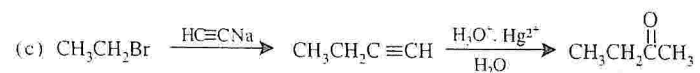
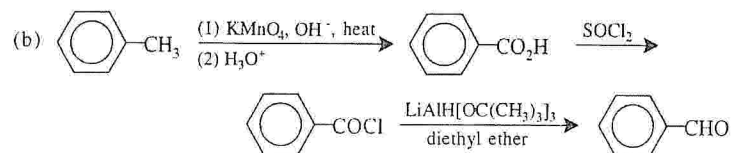
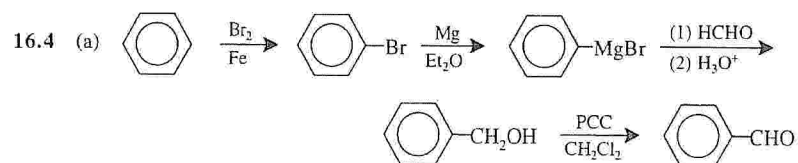
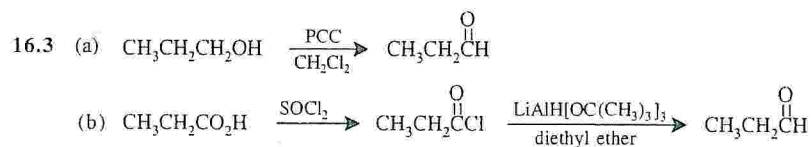
ALDEHYDES AND KETONES I.  
NUCLEOPHILIC ADDITION TO THE  
CARBONYL GROUP

## SOLUTIONS TO PROBLEMS



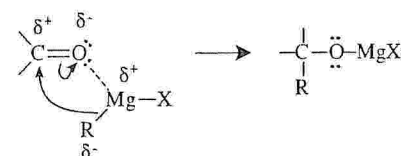


- 16.2 (a) 1-Pentanol, because its molecules form hydrogen bonds to each other.  
 (b) 2-Pentanol, because its molecules form hydrogen bonds to each other.  
 (c) Pentanal, because its molecules are more polar.  
 (d) 2-Phenylethanol, because its molecules form hydrogen bonds to each other.  
 (e) Benzyl alcohol because its molecules form hydrogen bonds to each other.



16.5 (a) The nucleophile is the negatively charged carbon of the Grignard reagent acting as a carbanion.

(b) The magnesium portion of the Grignard reagent acts as a Lewis acid and accepts an electron pair of the carbonyl oxygen. This acid-base interaction makes the carbonyl carbon even more positive and, therefore, even more susceptible to nucleophilic attack.



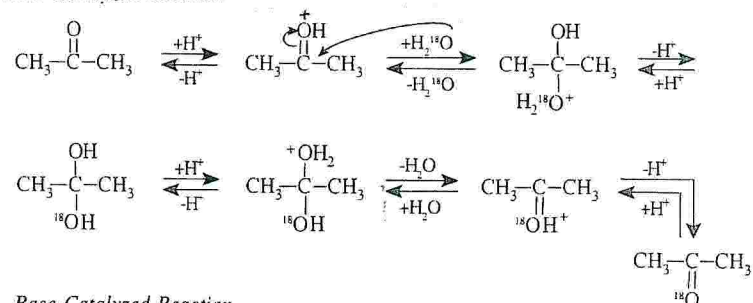
(c) The product that forms initially (above) is a magnesium derivative of an alcohol.

(d) On addition of water, the organic product that forms is an alcohol.

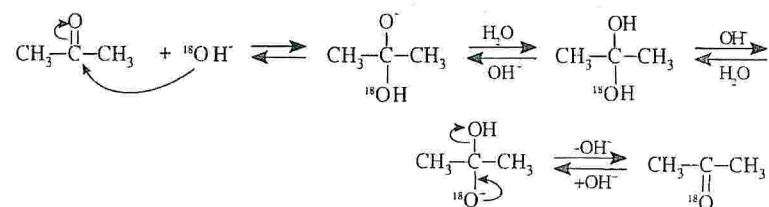
16.6 The nucleophile is a hydride ion.



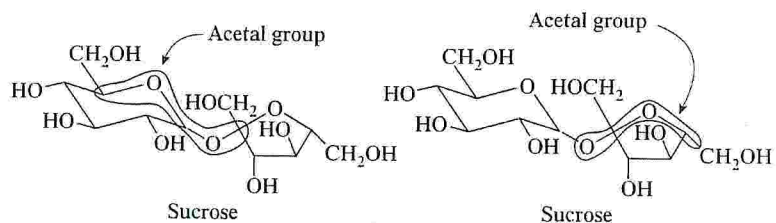
### 16.8 Acid-Catalyzed Reaction



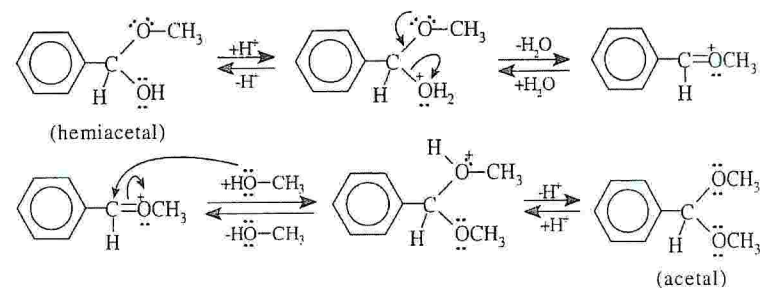
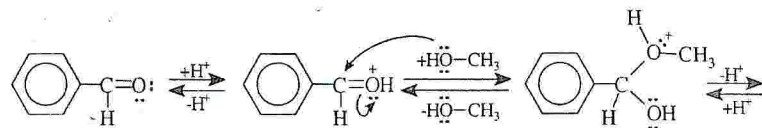
### Base-Catalyzed Reaction



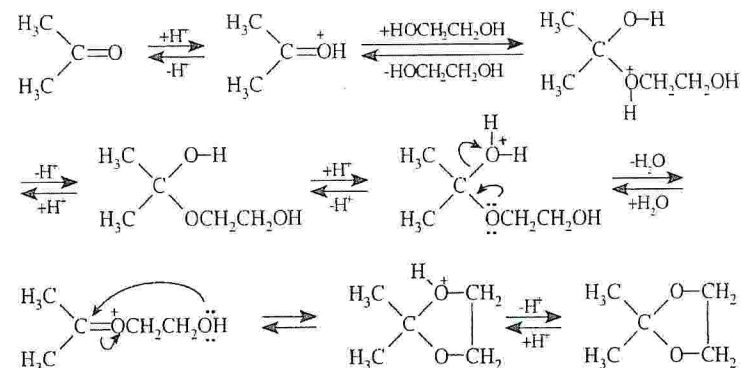
## 16.9



## 16.10



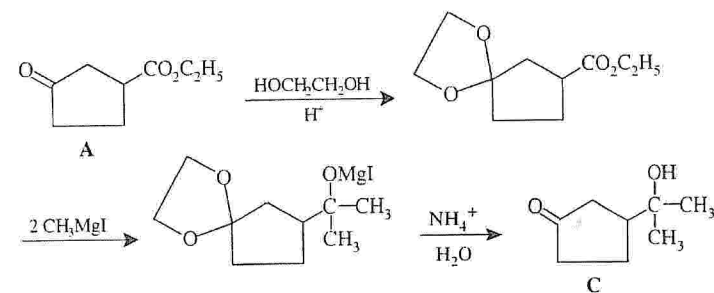
## 16.11



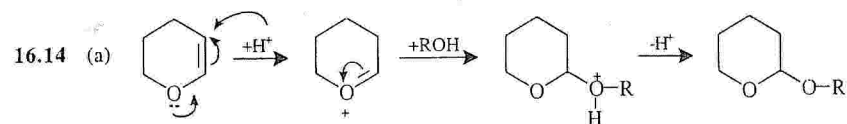
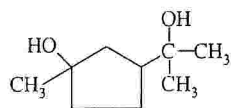
## 16.12



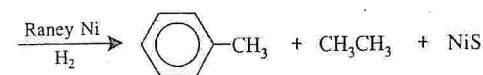
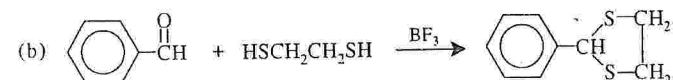
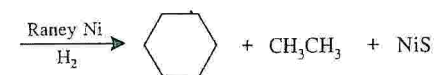
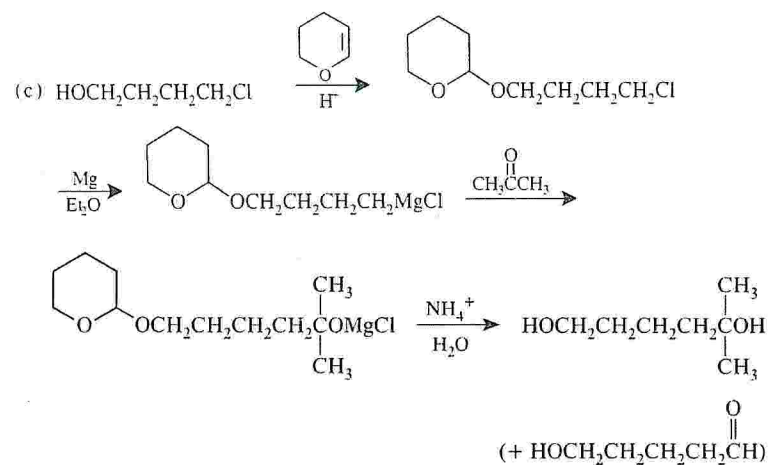
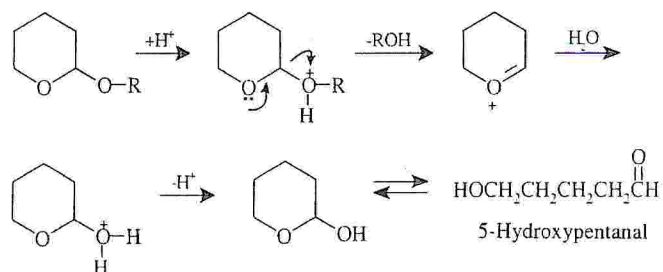
## 16.13 (a)



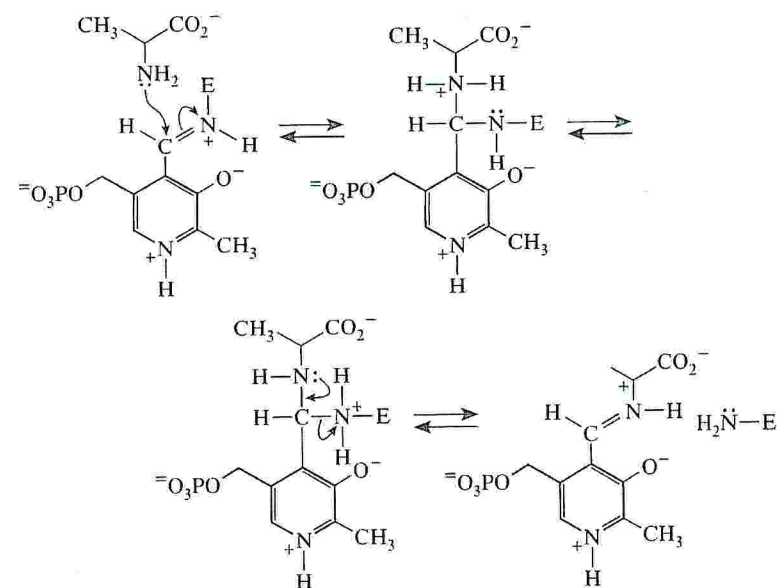
(b) Addition would take place at the ketone group as well as at the ester group. The product (after hydrolysis) would be.



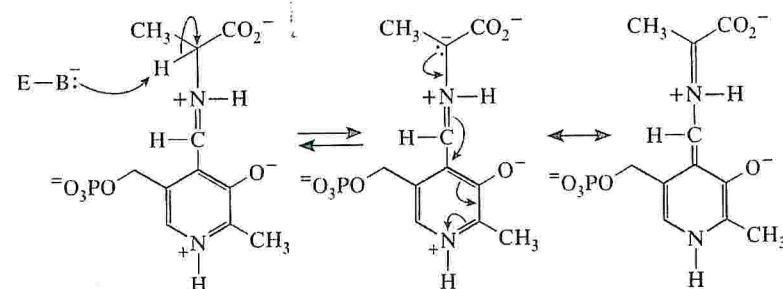
(b) Tetrahydropyranyl ethers are acetals; thus, they are stable in aqueous base and hydrolyze readily in aqueous acid.

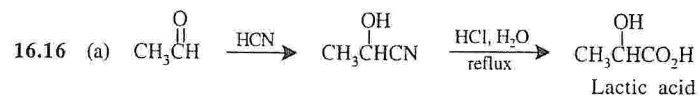


16.B1

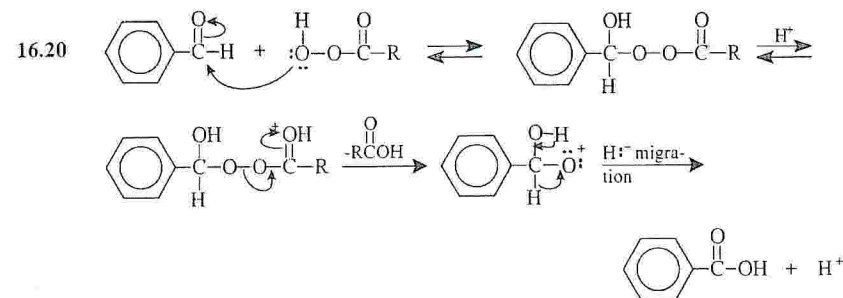
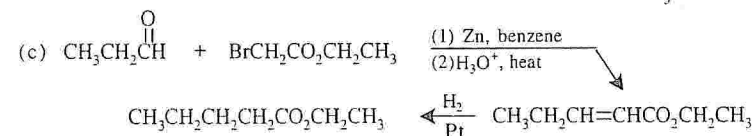
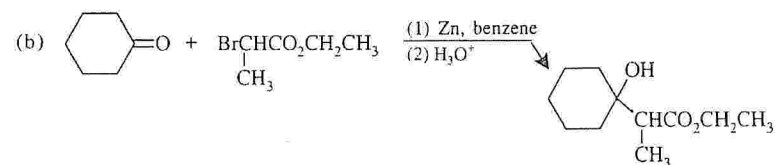
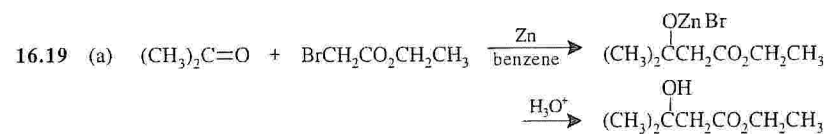
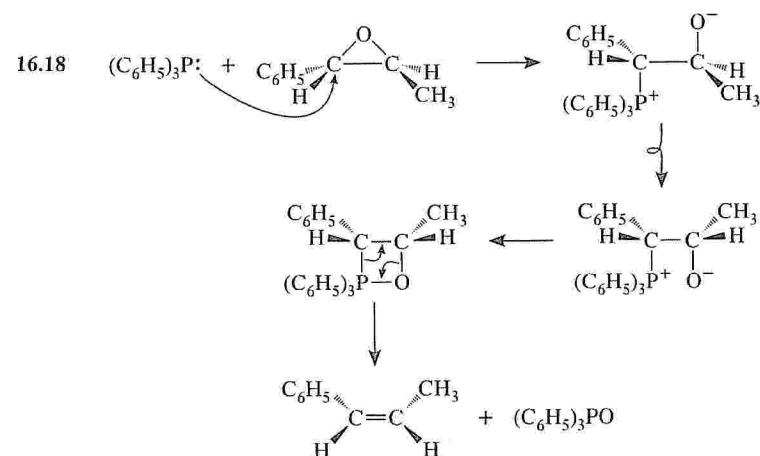
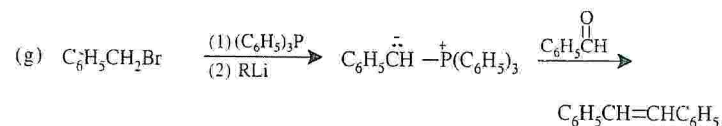
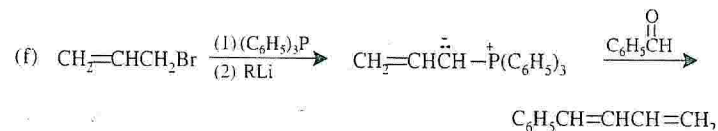
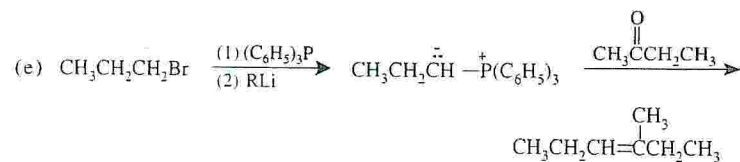
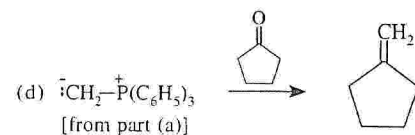
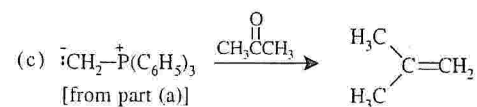
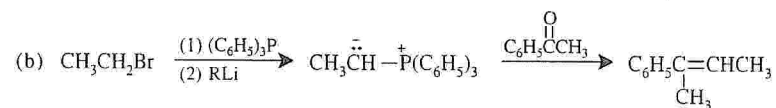
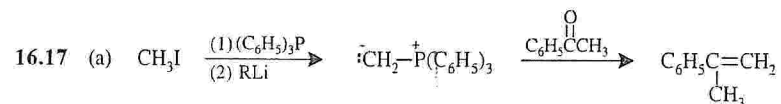


16.B2



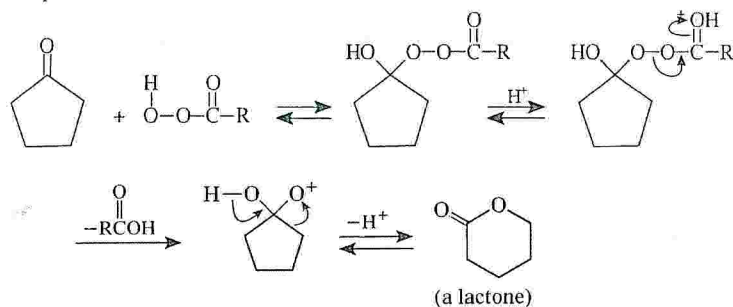


(b) A racemic form

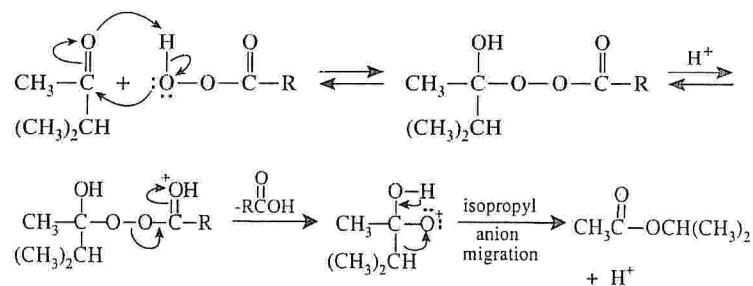




16.21 The product is a lactone, formed as follows:



16.22  $\text{CH}_3\text{C}(=\text{O})\text{OCH}(\text{CH}_3)_2$  The isopropyl group has a greater migratory aptitude than the methyl group. The mechanism is as follows:

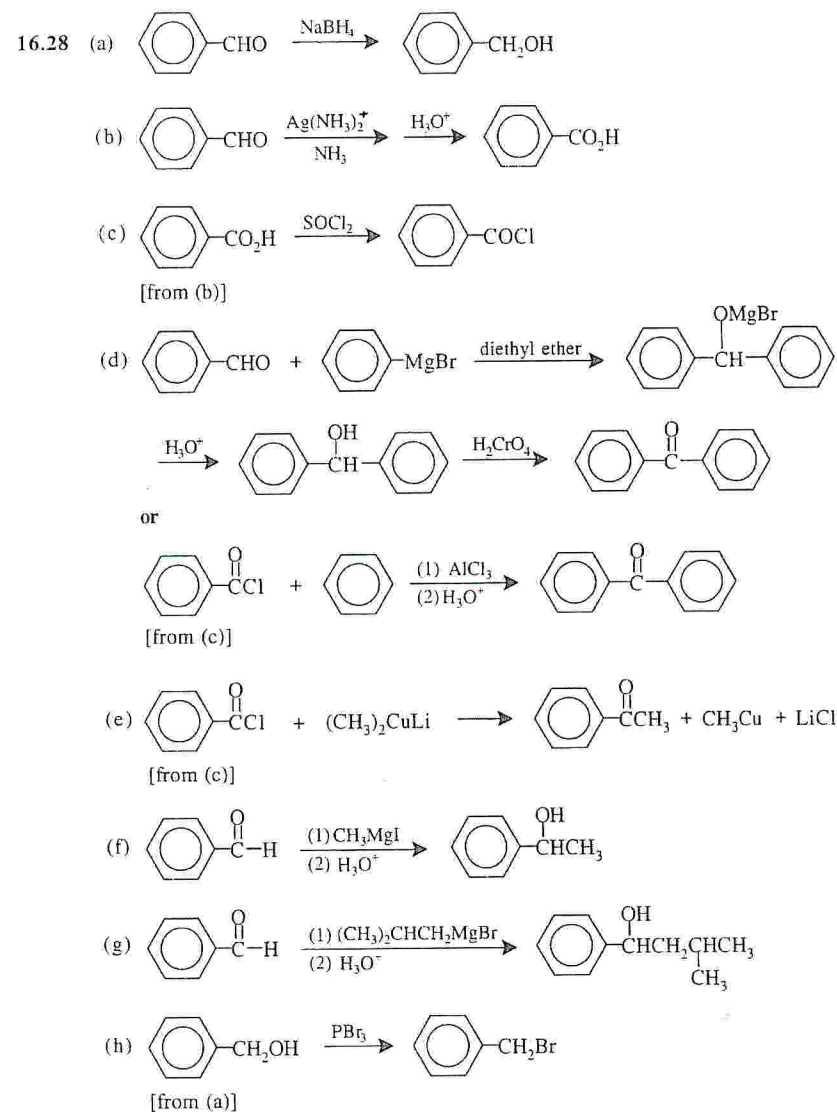
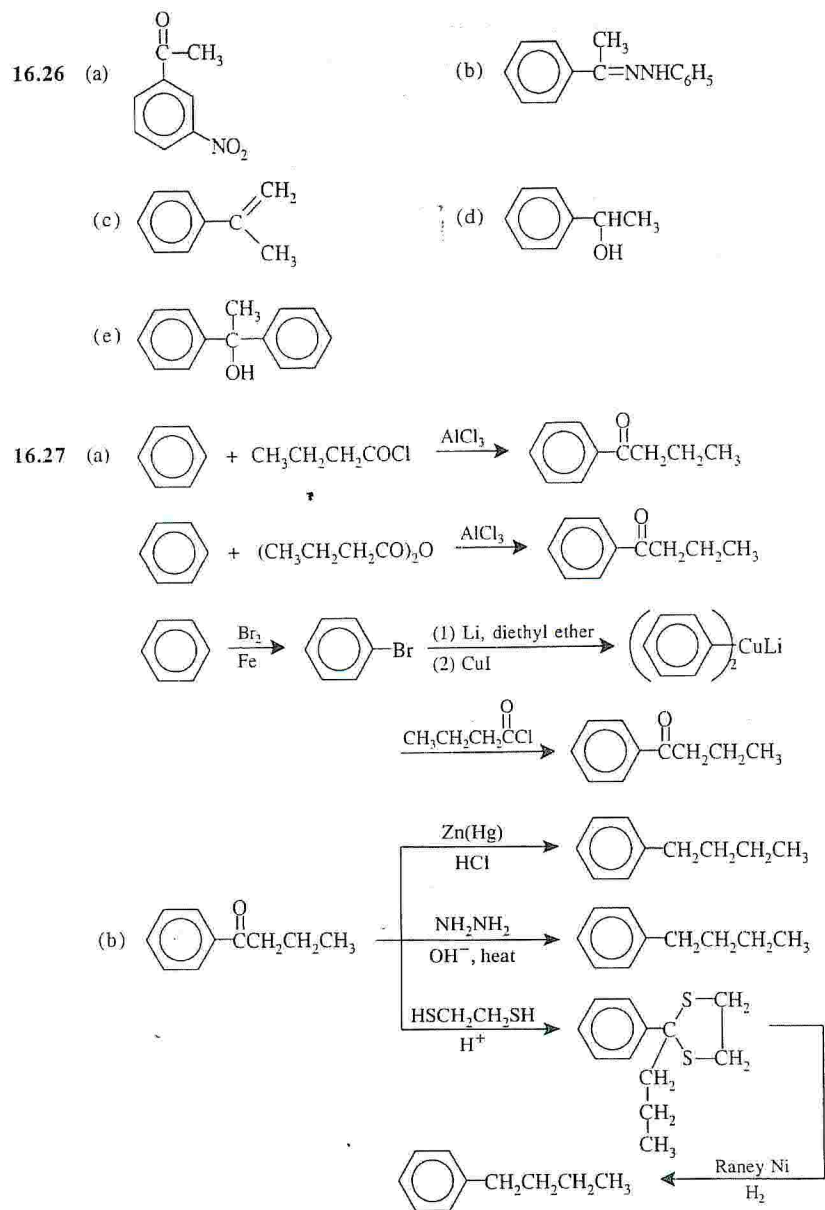


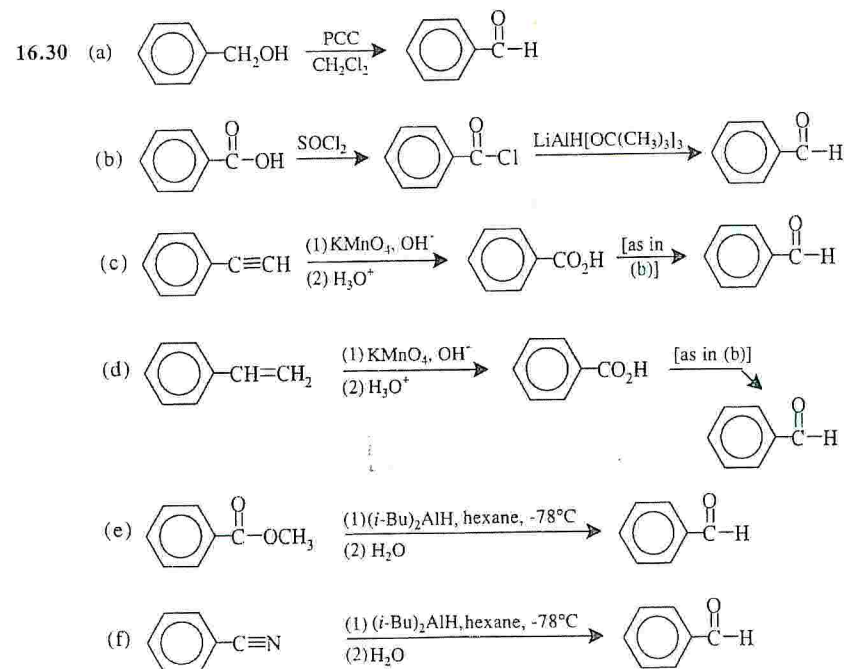
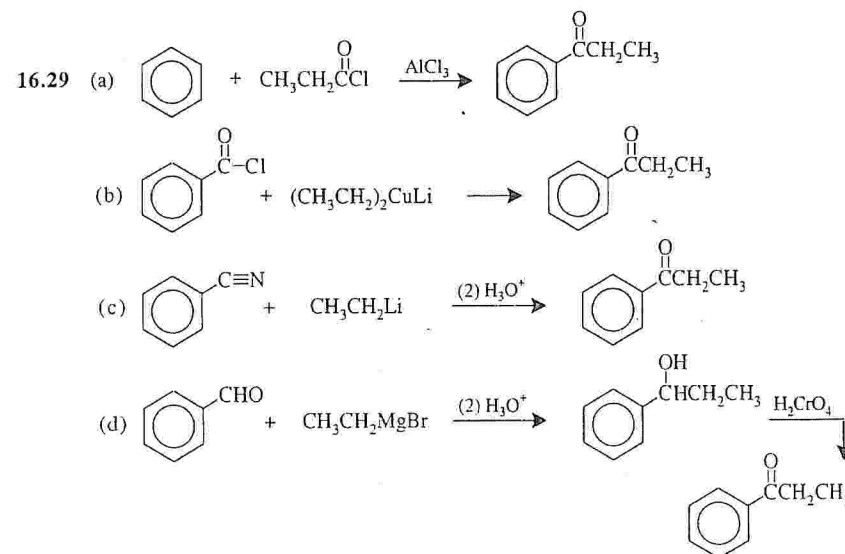
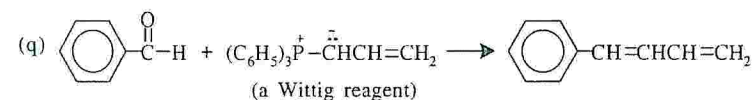
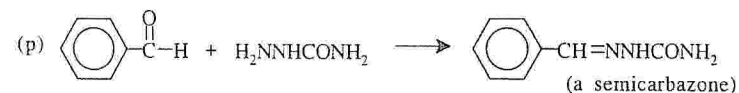
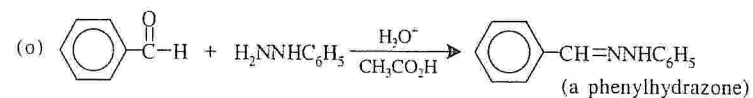
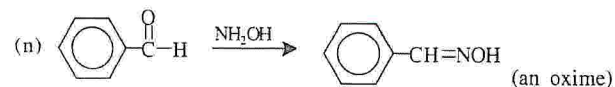
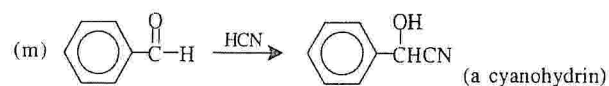
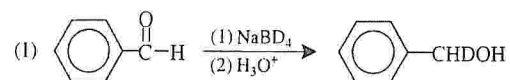
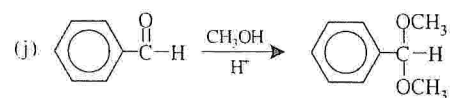
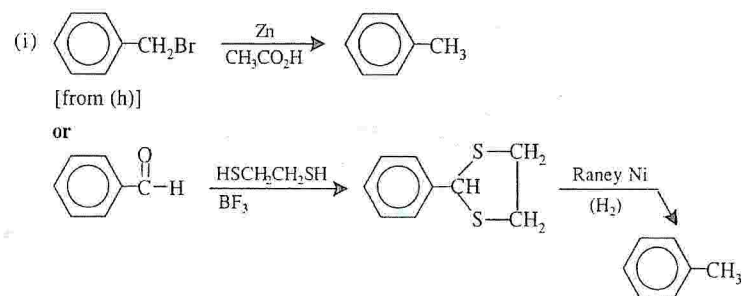
- 16.23
- |                                                      |                                                        |
|------------------------------------------------------|--------------------------------------------------------|
| (a) $\text{HCHO}$                                    | Methanal                                               |
| (b) $\text{CH}_3\text{CHO}$                          | Ethanal                                                |
| (c) $\text{C}_6\text{H}_5\text{CH}_2\text{CHO}$      | Phenylethanal                                          |
| (d) $\text{CH}_3\text{COCH}_3$                       | Propanone                                              |
| (e) $\text{CH}_3\text{COCH}_2\text{CH}_3$            | Butanone                                               |
| (f) $\text{CH}_3\text{COC}_6\text{H}_5$              | 1-Phenylethanone or methyl phenyl ketone               |
| (g) $\text{C}_6\text{H}_5\text{COC}_6\text{H}_5$     | Diphenylmethanone or diphenyl ketone                   |
| (h)                                                  | 2-Hydroxybenzaldehyde or <i>o</i> -hydroxybenzaldehyde |
| (i)                                                  | 4-Hydroxy-3-methoxybenzaldehyde                        |
| (j) $\text{CH}_3\text{CH}_2\text{COCH}_2\text{CH}_3$ | 3-Pentanone                                            |

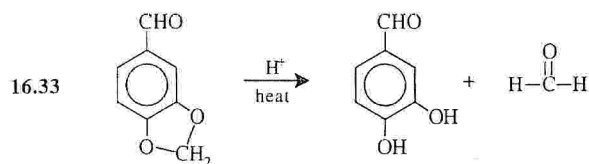
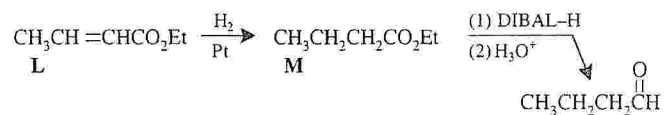
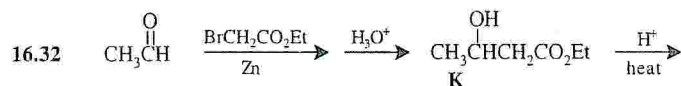
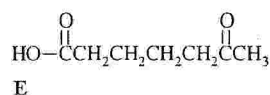
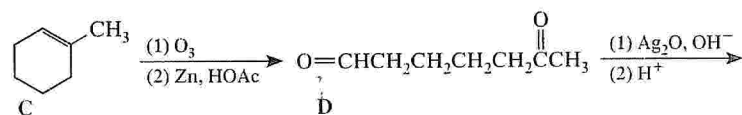
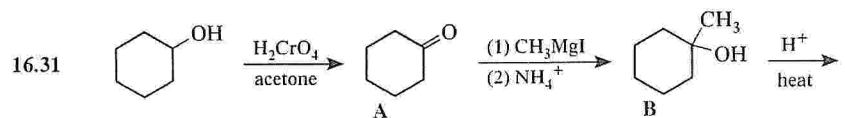
- |                                                                     |                          |
|---------------------------------------------------------------------|--------------------------|
| (k) $\text{CH}_3\text{CH}_2\text{COCH}(\text{CH}_3)_2$              | 2-Methyl-3-pentanone     |
| (l) $(\text{CH}_3)_2\text{CHCOCH}(\text{CH}_3)_2$                   | 2,4-Dimethyl-3-pentanone |
| (m) $\text{CH}_3(\text{CH}_2)_3\text{CO}(\text{CH}_2)_3\text{CH}_3$ | 5-Nonanone               |
| (n) $\text{CH}_3(\text{CH}_2)_2\text{CO}(\text{CH}_2)_2\text{CH}_3$ | 4-Heptanone              |
| (o) $\text{C}_6\text{H}_5\text{CH}=\text{CHCHO}$                    | 3-Phenyl-2-propenal      |

- 16.24
- |                                                           |                                                                               |
|-----------------------------------------------------------|-------------------------------------------------------------------------------|
| (a) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$          | (i) $\text{CH}_3\text{CH}_2\text{CHOHCH}_2\text{CO}_2\text{C}_2\text{H}_5$    |
| (b) $\text{CH}_3\text{CH}_2\text{CHOHC}_6\text{H}_5$      | (j) $\text{CH}_3\text{CH}_2\text{CO}_2\text{NH}_4^+ + \text{Ag}^+$            |
| (c) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$          | (k) $\text{CH}_3\text{CH}_2\text{CH}=\text{NOH}$                              |
| (d) $\text{CH}_3\text{CH}_2\text{C}(=\text{O})\text{O}^-$ | (l) $\text{CH}_3\text{CH}_2\text{CH}=\text{NNHCONH}_2$                        |
| (e) $\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$         | (m) $\text{CH}_3\text{CH}_2\text{CH}=\text{NNHC}_6\text{H}_5$                 |
| (f) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$          | (n) $\text{CH}_3\text{CH}_2\text{CO}_2\text{H}$                               |
| (g)                                                       | (o)                                                                           |
| (h) $\text{CH}_3\text{CH}_2\text{CH}=\text{CHCH}_3$       | (p) $\text{CH}_3\text{CH}_2\text{CH}_3 + \text{CH}_3\text{CH}_3 + \text{NiS}$ |

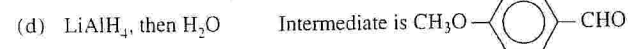
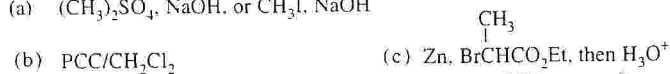
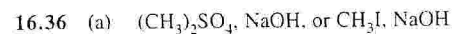
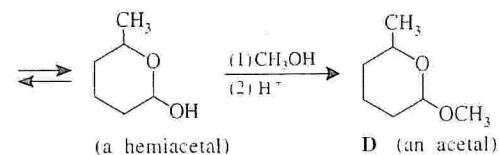
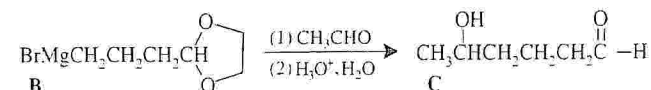
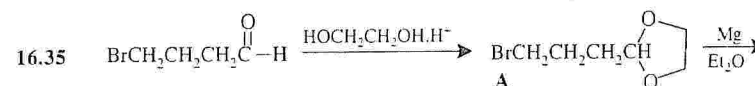
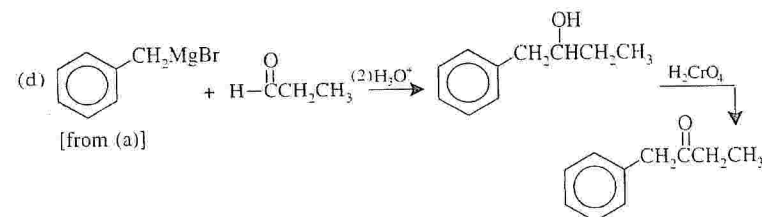
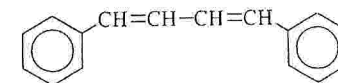
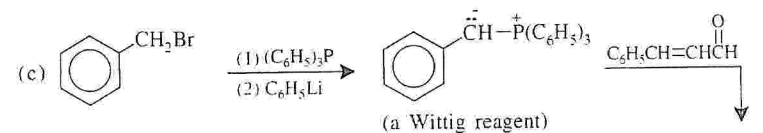
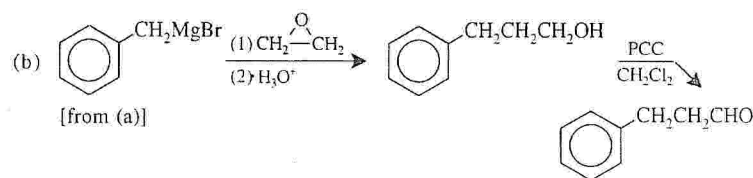
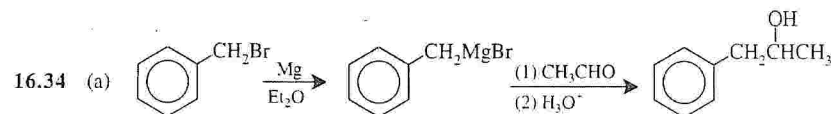
- 16.25
- |                                                                                             |                                                                               |
|---------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| (a) $\text{CH}_3\text{CHOHCH}_3$                                                            | (j) No reaction                                                               |
| (b)                                                                                         | (k) $\text{CH}_3\text{C}=\text{NOH}$                                          |
| (c) $\text{CH}_3\text{CHOHCH}_3$                                                            | (l) $\text{CH}_3\text{C}=\text{NNHCONH}_2$                                    |
| (d) No reaction                                                                             | (m) $\text{CH}_3\text{C}=\text{NNHC}_6\text{H}_5$                             |
| (e) $\text{CH}_3\text{C}(=\text{CH}_2)\text{CH}_3$                                          | (n) No reaction                                                               |
| (f) $\text{CH}_3\text{CHOHCH}_3$                                                            | (o)                                                                           |
| (g)                                                                                         | (p) $\text{CH}_3\text{CH}_2\text{CH}_3 + \text{CH}_3\text{CH}_3 + \text{NiS}$ |
| (h) $\text{CH}_3\text{CH}=\text{C}(\text{CH}_3)_2$                                          |                                                                               |
| (i) $\text{CH}_3\text{C}(\text{OH})(\text{CH}_3)\text{CH}_2\text{CO}_2\text{C}_2\text{H}_5$ |                                                                               |



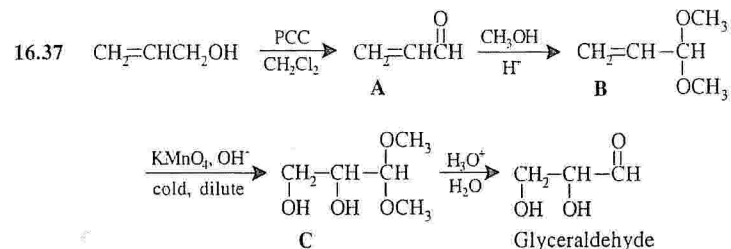




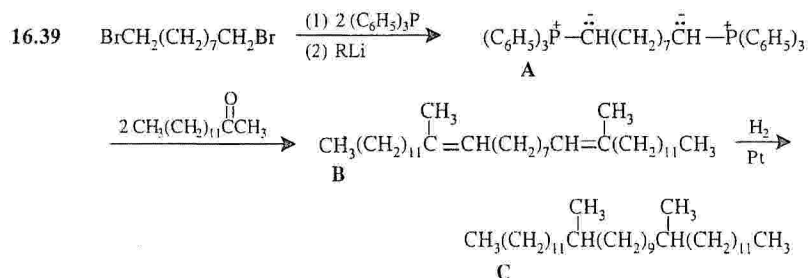
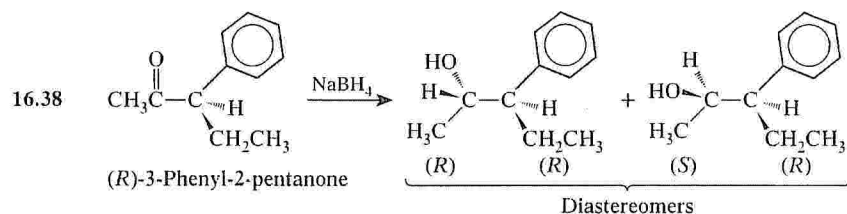
The compound  $\text{C}_7\text{H}_6\text{O}_3$  is 3,4-dihydroxybenzaldehyde. The reaction involves hydrolysis of the acetal of formaldehyde.



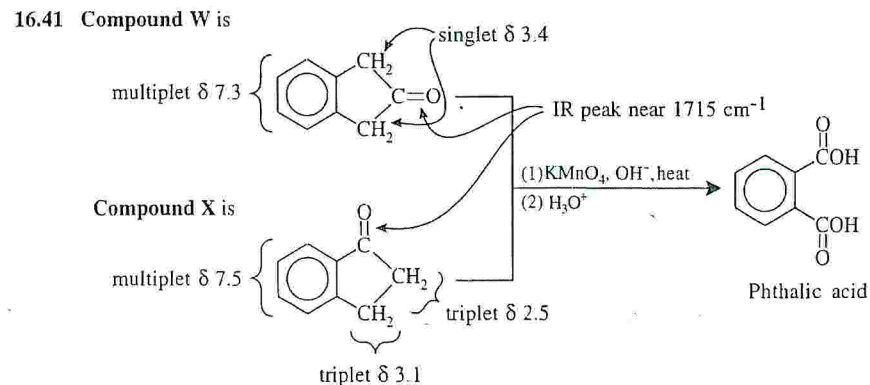




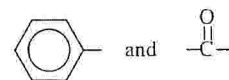
The product would be racemic as no chiral reagents were used.



- 16.40** (a)  $\text{Ag}(\text{NH}_3)_2^+\text{OH}^-$  (positive test with benzaldehyde)  
 (b)  $\text{Ag}(\text{NH}_3)_2^+\text{OH}^-$  (positive test with hexanal)  
 (c) Concentrated  $\text{H}_2\text{SO}_4$  (2-hexanone is soluble)  
 (d)  $\text{CrO}_3$  in  $\text{H}_2\text{SO}_4$  (positive test with 2-hexanol)  
 (e)  $\text{Br}_2$  in  $\text{CCl}_4$  (decolorization with  $\text{C}_6\text{H}_5\text{CH}=\text{CHCO}_2\text{C}_6\text{H}_5$ )  
 (f)  $\text{Ag}(\text{NH}_3)_2^+\text{OH}^-$  (positive test with pentanal)  
 (g)  $\text{Br}_2$  in  $\text{CCl}_4$  (immediate decolorization occurs with enol form)  
 (h)  $\text{Ag}(\text{NH}_3)_2^+\text{OH}^-$  (positive test with cyclic hemiacetal)



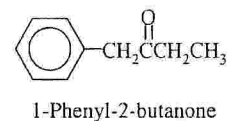
- 16.42** Each  $^1\text{H}$  NMR spectrum (Figs. 16.4 and 16.5) has a five-hydrogen peak near  $\delta$  7.2, suggesting the **Y** and **Z** each has a  $\text{C}_6\text{H}_5$ -group. The IR spectrum of each compound shows a strong peak near  $1710\text{ cm}^{-1}$ . This absorption indicates that each compound has a  $\text{C}=\text{O}$  group not adjacent to the phenyl group. We have, therefore, the following pieces,



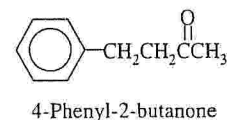
If we subtract the atoms of these pieces from the molecular formula,

We are left with, 
$$\frac{\text{C}_{10}\text{H}_{12}\text{O}}{-\text{C}_7\text{H}_5\text{O}} (\text{C}_6\text{H}_5 + \text{C}=\text{O})$$

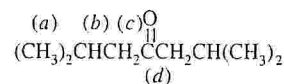
In the  $^1\text{H}$  NMR spectrum of **Y**, we see an ethyl group [triplet,  $\delta$  1.0 (3H) and quartet,  $\delta$  2.45 (2H)] and an unsplit  $-\text{CH}_2-$  group [singlet,  $\delta$  3.7 (2H)]. This means that **Y** must be



In the  $^1\text{H}$  NMR spectrum of **Z**, we see an unsplit  $-\text{CH}_3$  group [singlet,  $\delta$  2.1 (3H)] and two triplets at  $\delta$  2.7 and 2.9. This means **Z** must be



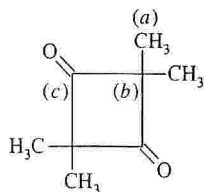
- 16.43** That compound **A** forms a phenylhydrazone, gives a negative Tollens' test, and gives an IR band near  $1710\text{ cm}^{-1}$  indicates that **A** is a ketone. The  $^{13}\text{C}$  spectrum of **A** contains only four signals indicating that **A** has a high degree of symmetry. The information from the DEPT  $^{13}\text{C}$  NMR spectra enables us to conclude that **A** is diisobutyl ketone:



Assignments:

- (a)  $\delta$  22.6  
(b)  $\delta$  24.4  
(c)  $\delta$  52.3  
(d)  $\delta$  210.0

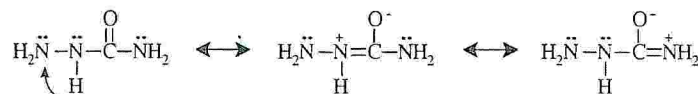
- 16.44** That the  $^{13}\text{C}$  spectrum of **B** contains only three signals indicates that **B** has a highly symmetrical structure. The information from DEPT spectra indicates the presence of equivalent methyl groups ( $\text{CH}_3$  at  $\delta$  18.8), equivalent  $-\text{C}-$  groups (at  $\delta$  70.4), and equivalent  $\text{C}=\text{O}$  groups (at  $\delta$  215.0). These features allow only one possible structure for **B**:



Assignments:

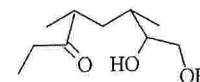
- (a)  $\delta$  18.8  
(b)  $\delta$  70.4  
(c)  $\delta$  215.0

- 16.45** The two nitrogen atoms of semicarbazide that are adjacent to the  $\text{C}=\text{O}$  group bear partial positive charges because of resonance contributions made by the second and third structures below.

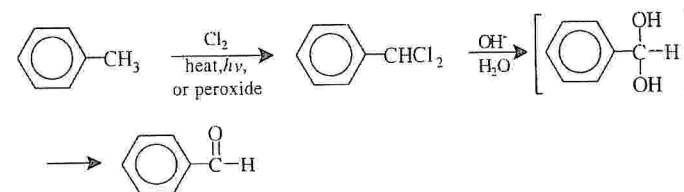


Only this nitrogen is nucleophilic.

- 16.46** Hydrolysis of the acetal linkage of multistriatin produces the ketodiol below.

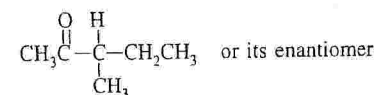


- 16.47**

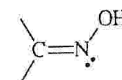


The *gem*-diol formed in the alkaline hydrolysis step readily loses water to form the aldehyde.

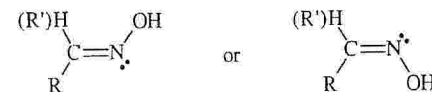
- 16.48**



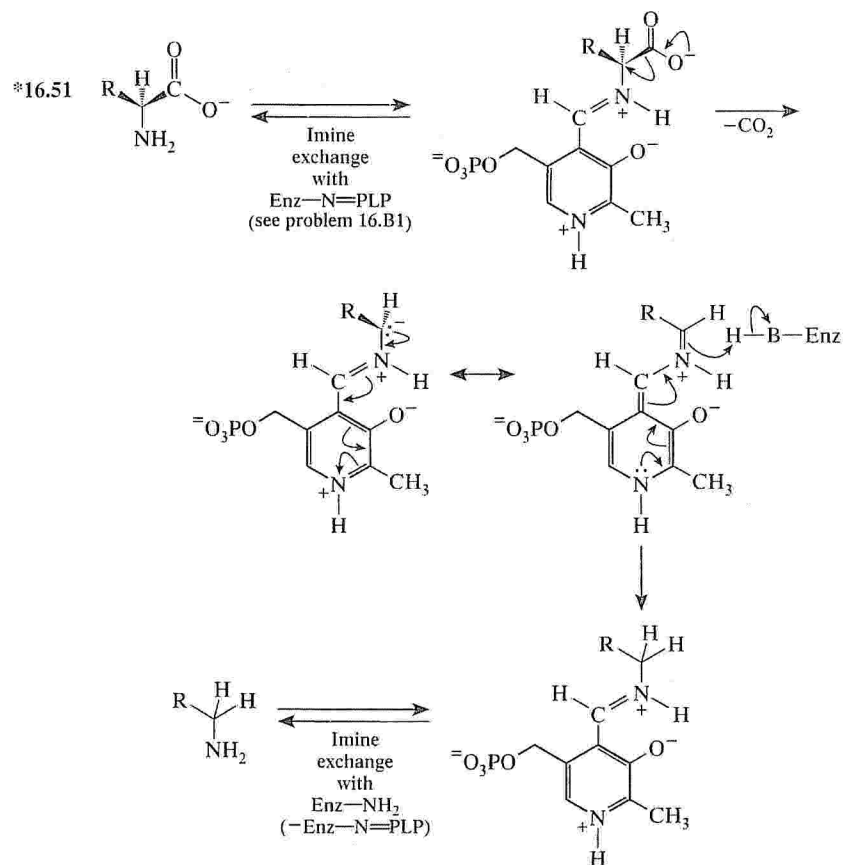
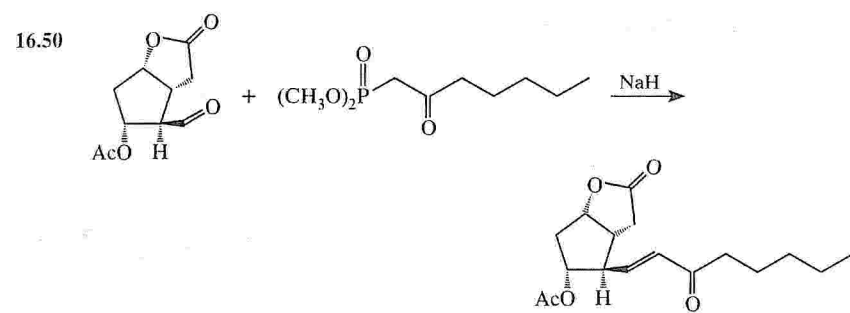
- 16.49** The general formula for an oxime is



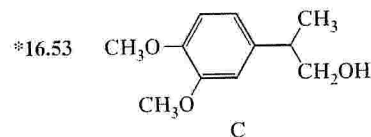
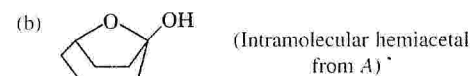
Both carbon and nitrogen are  $sp^2$  hybridized; the electron pair on nitrogen occupies one  $sp^2$  orbital. Aldoximes and ketoximes can exist in either of these two stereoisomeric forms:



This type of stereoisomerism is also observed in the case of other compounds that possess the  $\text{C}=\text{N}$  group, for example, phenylhydrazones and semicarbazones.



\*16.52 (a) O—H stretch at about  $3300\text{ cm}^{-1}$ ; C=O stretch at about  $1710\text{ cm}^{-1}$



## QUIZ

16.1 Which Wittig reagent could be used to synthesize  $\text{C}_6\text{H}_5\text{CH}=\text{CHCH}_2\text{CH}_3$ ? (Assume any other needed reagents are available.)

- (a)  $\text{C}_6\text{H}_5\text{CHP}^+(\text{C}_6\text{H}_5)_3$  (d) More than one of these  
 (b)  $\text{C}_6\text{H}_5\text{CH}=\text{CHCHP}^+(\text{C}_6\text{H}_5)_3$  (e) None of these  
 (c)  $\text{CH}_3\text{CH}_2\text{CHP}^+(\text{C}_6\text{H}_5)_3$

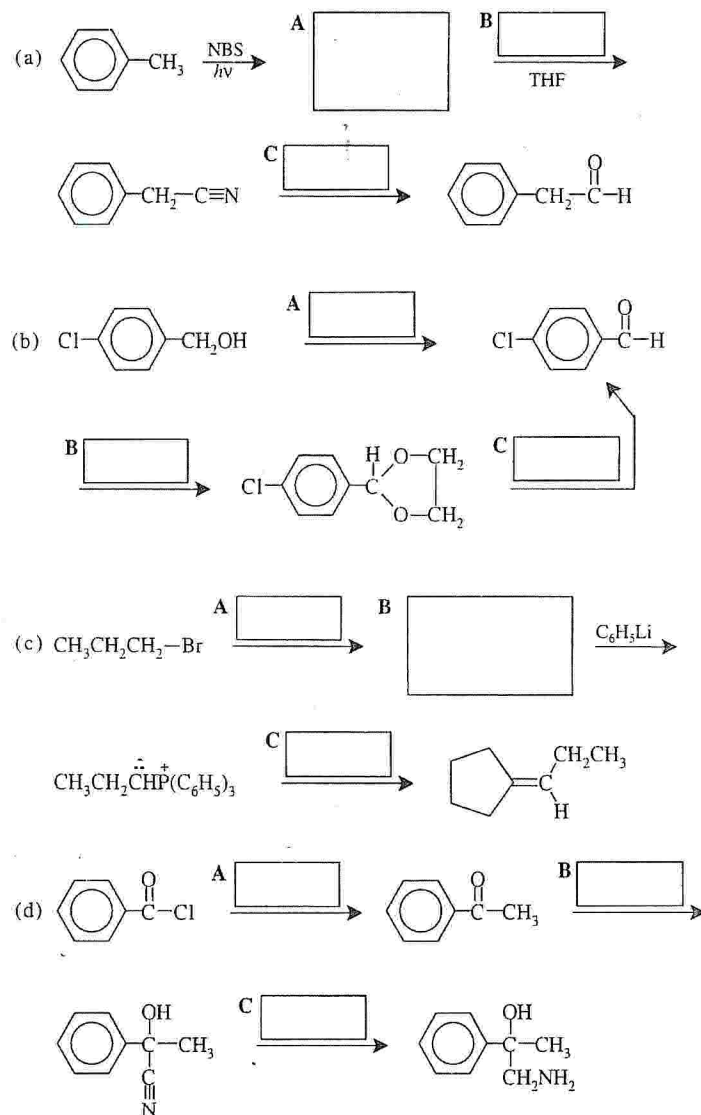
16.2 Which compound is an acetal?

- (a)  $\text{C}_6\text{H}_5\text{CHOCH}_3$  (d) More than one of these  
 (b) (e) None of these  
 (c)

16.3 Which reaction sequence could be used to convert  $\text{C}_6\text{H}_{13}\text{C}\equiv\text{CH}$  to  $\text{C}_6\text{H}_{13}\text{C}(=\text{O})\text{CH}_3$ ?

- (a)  $\text{O}_3$ , then  $\text{Zn}$ ,  $\text{HOAc}$ , then  $\text{AlCl}_3$ , the  $\text{CH}_3\text{CO}_2\text{H}$   
 (b)  $\text{H}_2\text{SO}_4$ ,  $\text{HgSO}_4$ ,  $\text{H}_2\text{O}$ , heat  
 (c)  $\text{HCl}$ , then  $\text{CH}_3\text{CO}_2\text{H}$   
 (d)  $\text{O}_3$ , then  $\text{Zn}$ ,  $\text{HOAc}$ , then  $\text{H}_2\text{SO}_4$ ,  $\text{HgSO}_4$ ,  $\text{H}_2\text{O}$ , heat  
 (e)  $\text{CH}_3\text{CO}_2\text{H}$ , then  $\text{H}_2\text{O}_2$ ,  $\text{OH}^-/\text{H}_2\text{O}$

16.4 Complete the following syntheses. If more than one step is required for a transformation, list them as (1), (2), (3), and so on.



## 17

ALDEHYDES AND KETONES II.  
ALDOL REACTIONS

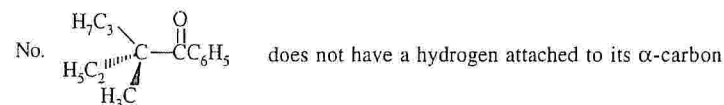
## SOLUTIONS TO PROBLEMS

17.1

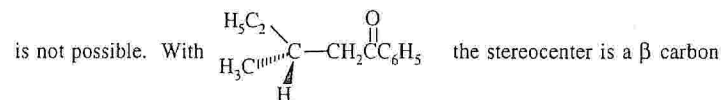
2,4-Cyclohexadien-1-one  
(keto form)Phenol  
(enol form)

The enol form is aromatic, and it is therefore stabilized by the resonance energy of the benzene ring.

17.2

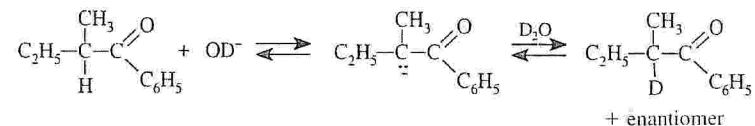
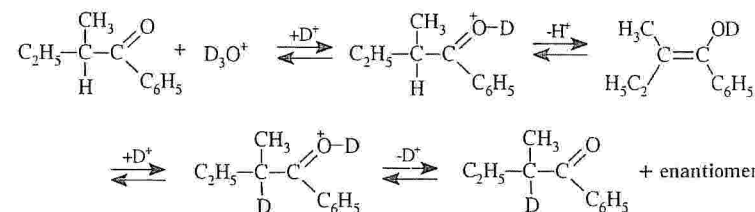


atom (which is a stereocenter) and thus enol formation involving the stereocenter

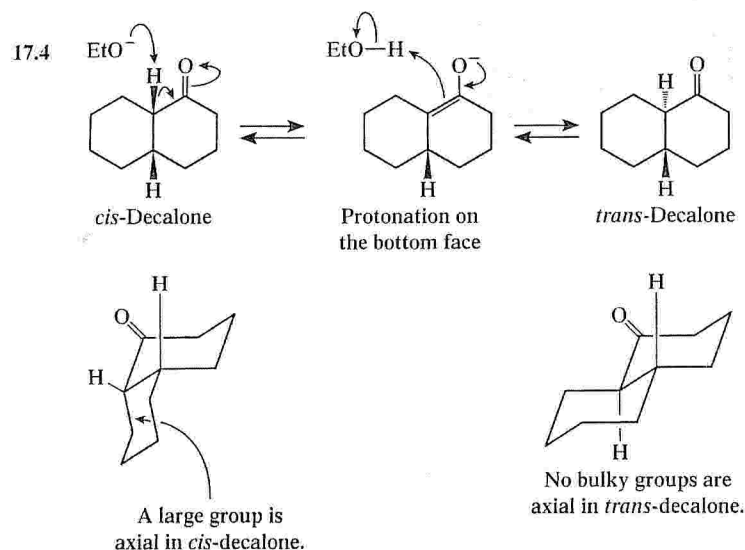


and thus enol formation does not affect it.

17.3

In  $\text{OD}^+/\text{D}_2\text{O}$ :In  $\text{D}_3\text{O}^+/\text{D}_2\text{O}$ :



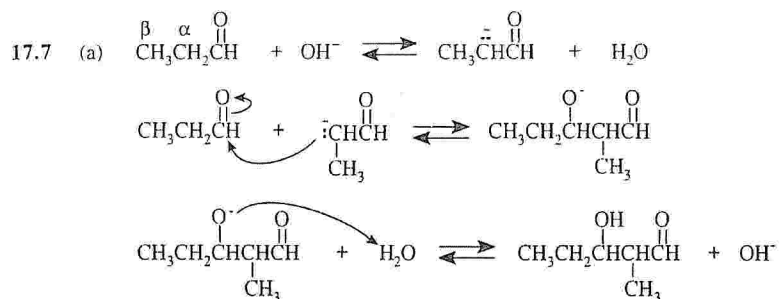


17.5 The reaction is said to be "base promoted" because base is consumed as the reaction takes place. A catalyst is, by definition, not consumed.

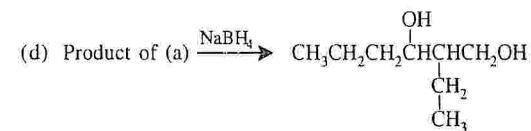
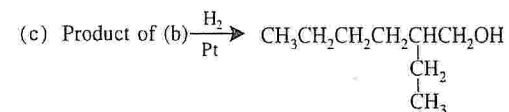
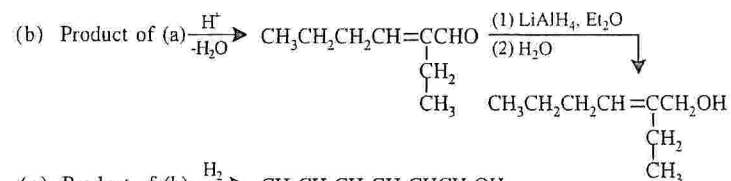
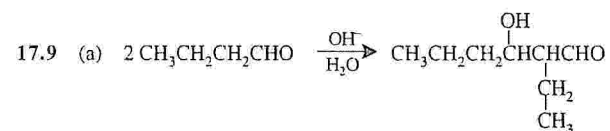
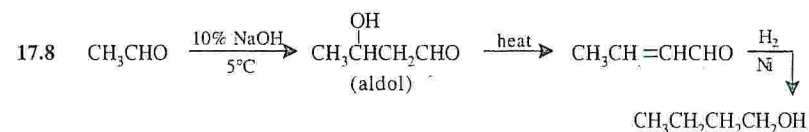
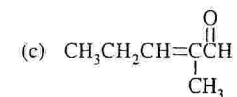
17.6 (a) The slow step in base-catalyzed racemization is the same as that in base-promoted halogenation—the formation of an enolate ion. (Formation of an enolate ion from *sec*-butyl phenyl ketone leads to racemization because the enolate ion is achiral. When it accepts a proton, it yields a racemic form.) The slow step in acid-catalyzed racemization is also the same as that in acid-catalyzed halogenation—the formation of an enol. (The enol, like the enolate ion, is achiral and tautomerizes to yield a racemic form of the ketone.)

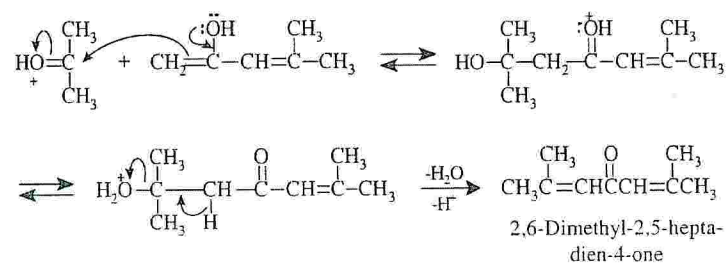
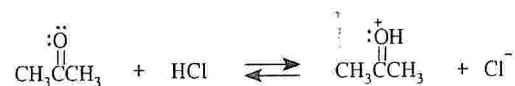
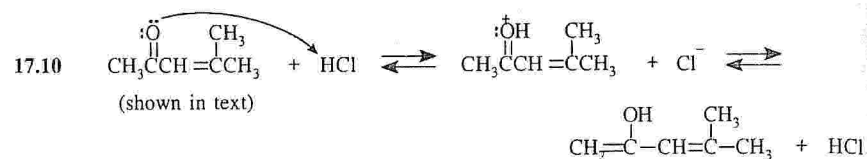
(b) According to the mechanism given, the slow step for acid-catalyzed iodination (formation of the enol) is the same as that for acid-catalyzed bromination. Thus, we would expect both reactions to occur at the same rate.

(c) Again, the slow step for both reactions (formation of the enolate ion) is the same, and consequently, both reactions take place at the same rate.

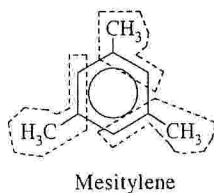


(b) For  $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{CH}_2\text{CHO}$  to form, a hydroxide ion would have to remove a  $\beta$  proton in the first step. This does not happen because the anion that would be produced, that is,  $\text{:CH}_2\text{CH}_2\text{CHO}$ , cannot be stabilized by resonance.

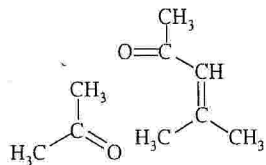




- 17.11 Drawing the molecules as they will appear in the final product helps to visualize the necessary steps:

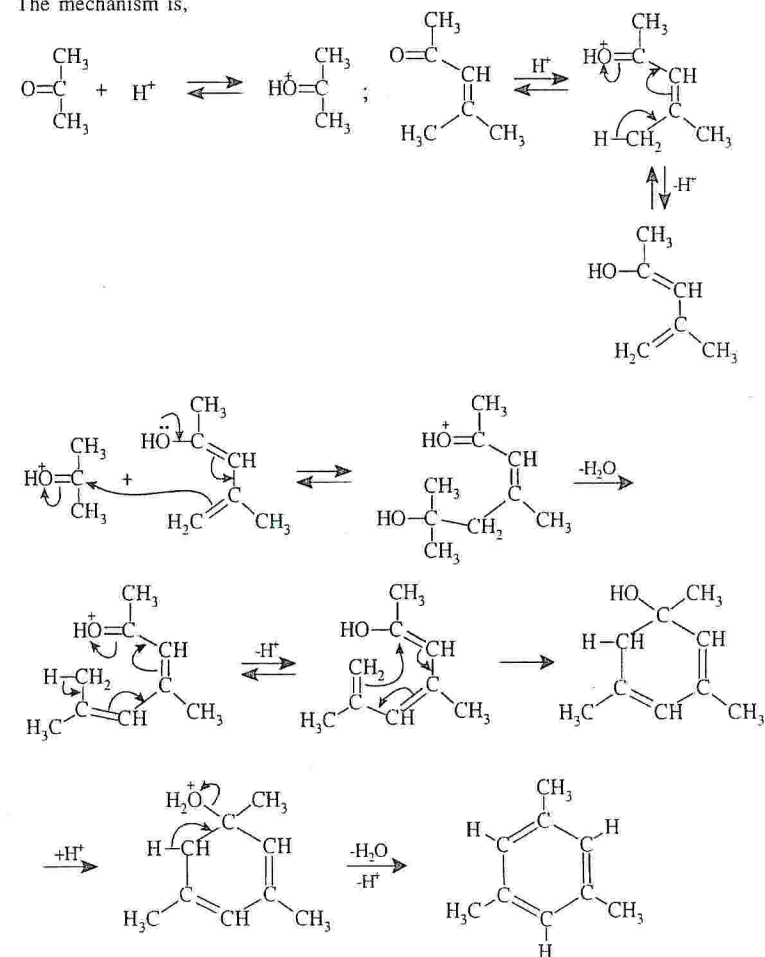


The two molecules that lead to mesitylene are shown as follows:

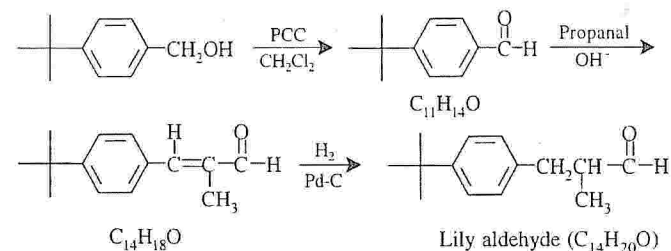


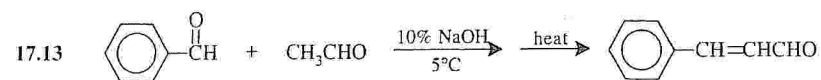
This molecule (4-methyl-3-penten-2-one) is formed by an acid-catalyzed condensation between two molecules of acetone as shown in the text.

The mechanism is,

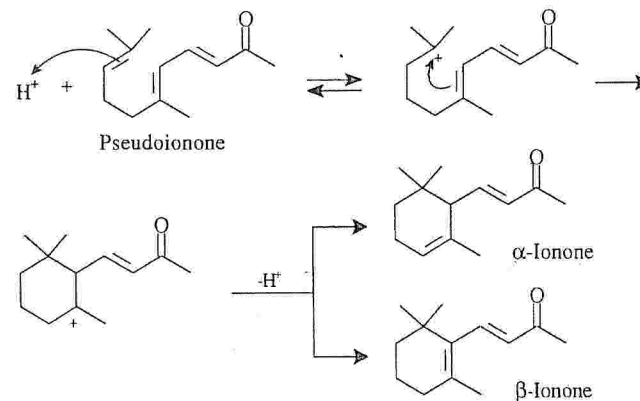
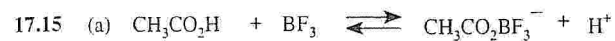
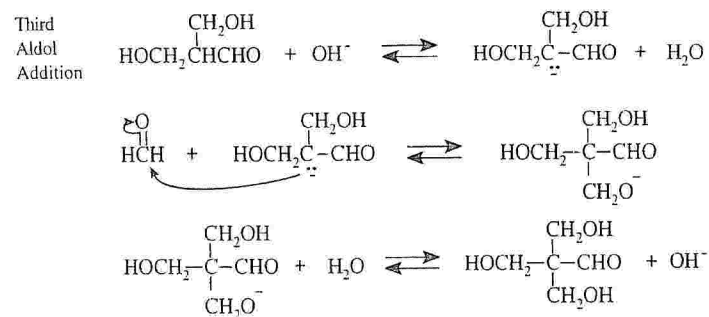
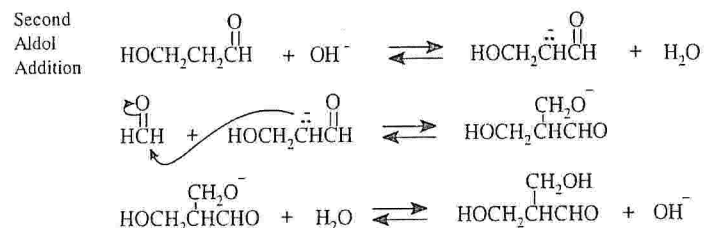
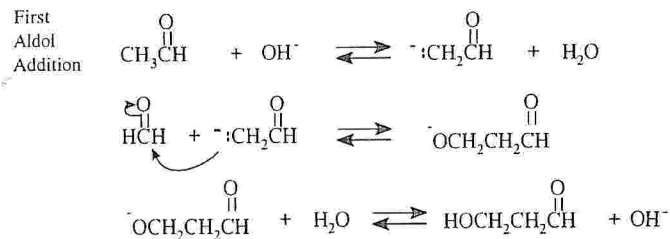


17.12



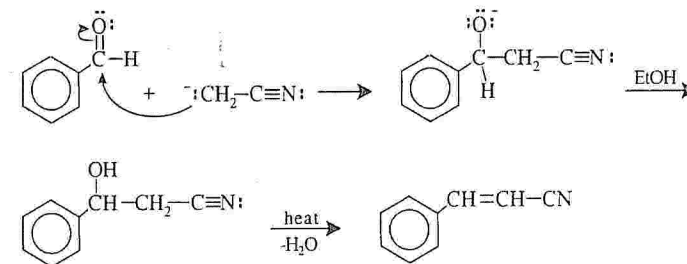
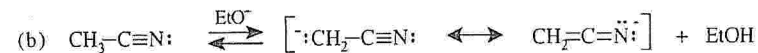
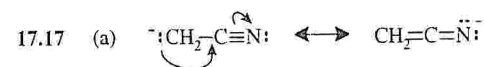
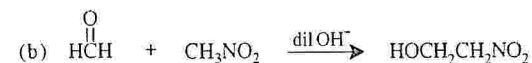
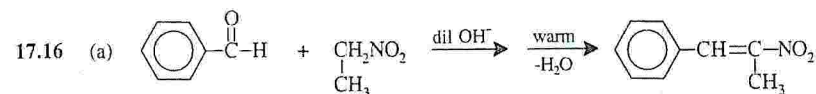


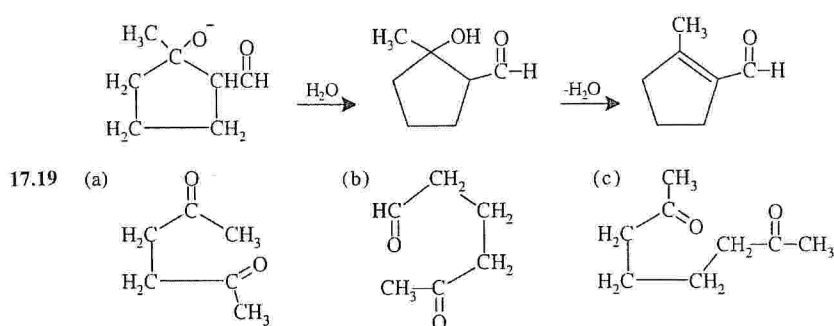
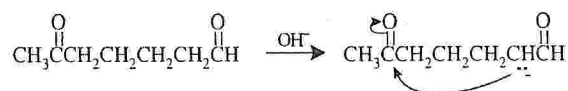
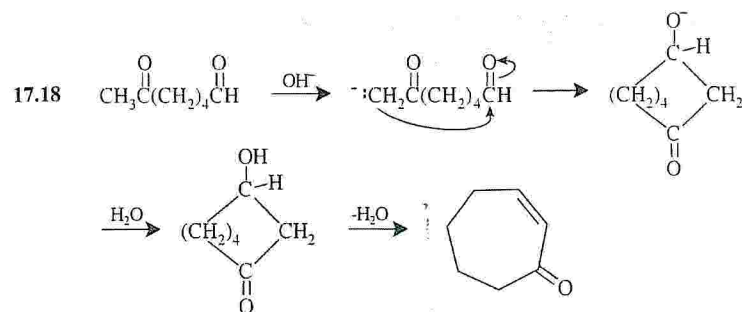
17.14 Three successive aldol additions occur.



(b) In  $\beta$ -ionone both double bonds and the carbonyl group are conjugated; thus it is more stable.

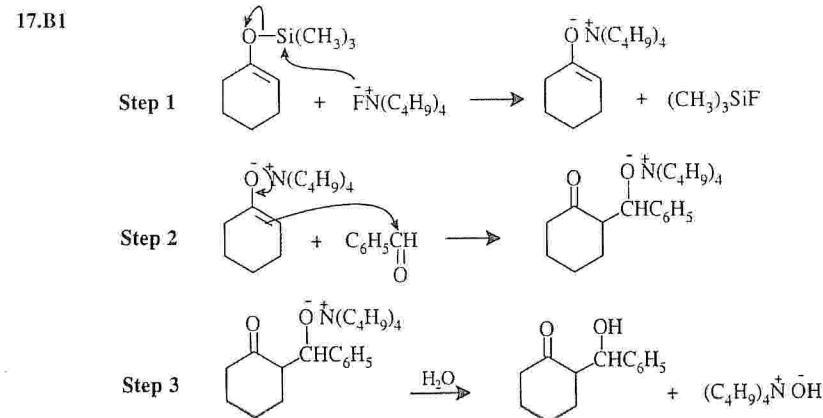
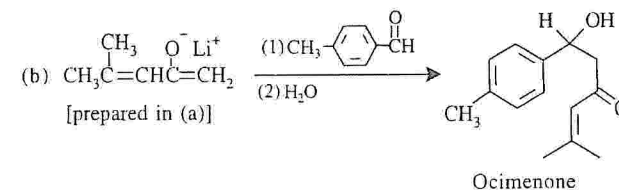
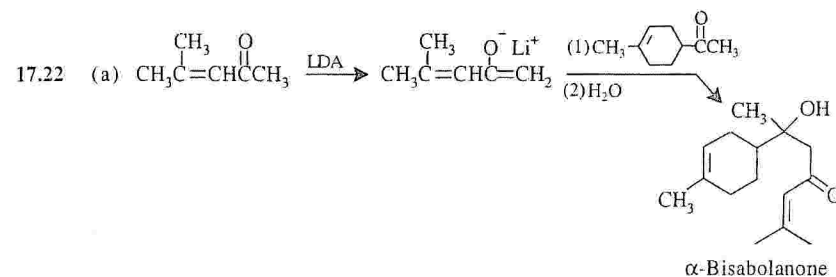
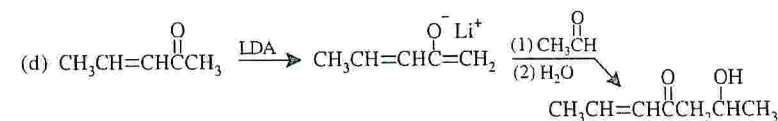
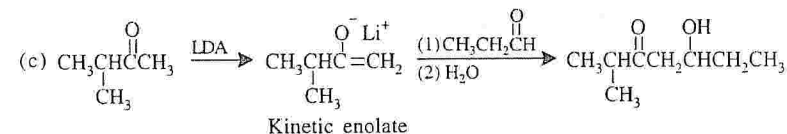
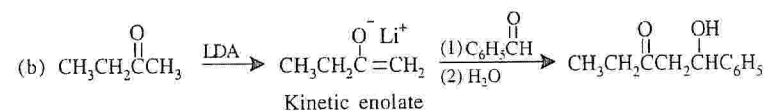
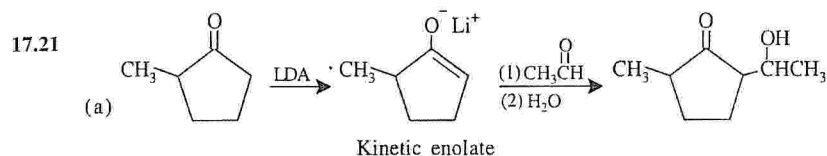
(c)  $\beta$ -Ionone, because it is a fully conjugated unsaturated system.



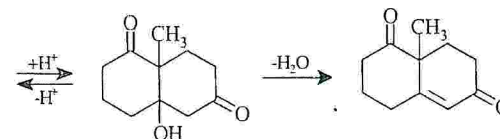
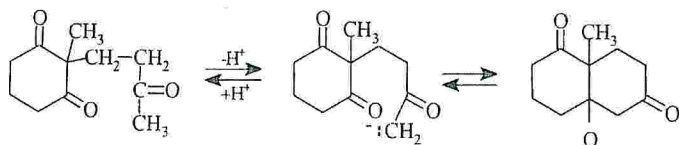
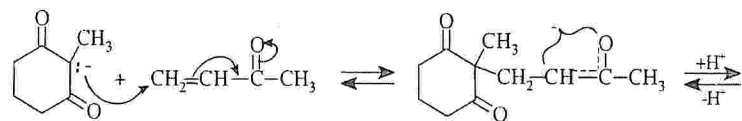
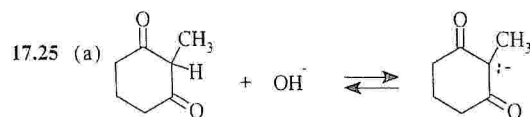
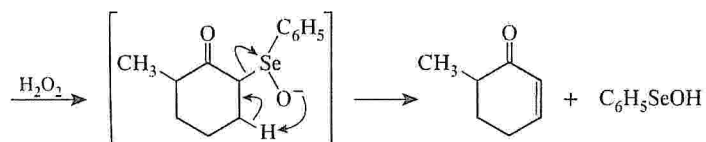
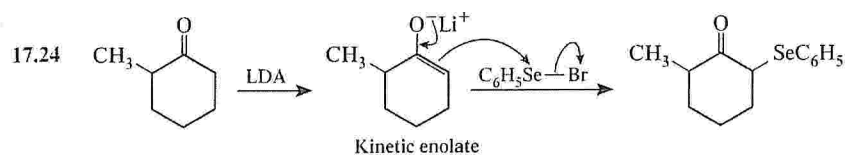
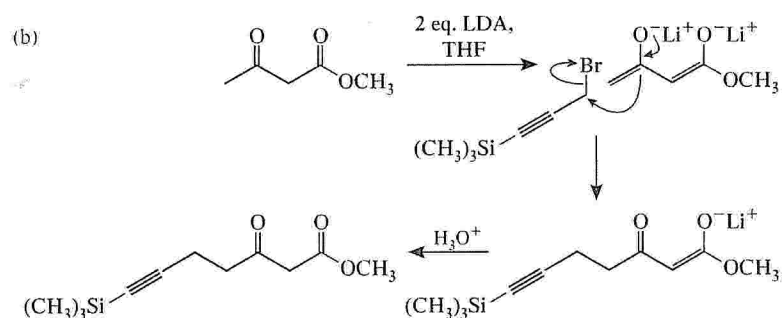
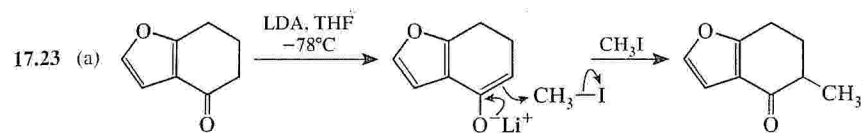


Notice that starting compounds are drawn so as to indicate which atoms are involved in the cyclization reaction.

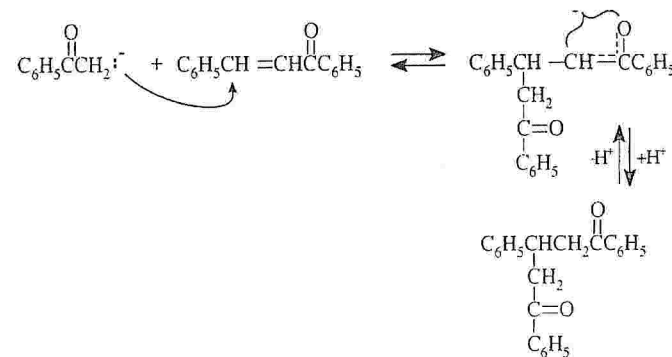
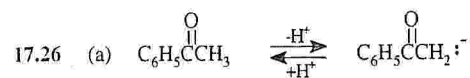
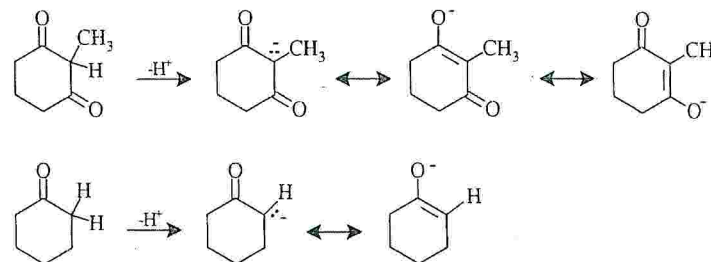
17.20 It is necessary for conditions to favor the intramolecular reaction rather than the intermolecular one. One way to create these conditions is to use very dilute solutions when we carry out the reaction. When the concentration of the compound to be cyclized is very low (i.e., when we use what we call a "high dilution technique"), the probability is greater that one end of a molecule will react with the other end of that same molecule rather than with a different molecule.

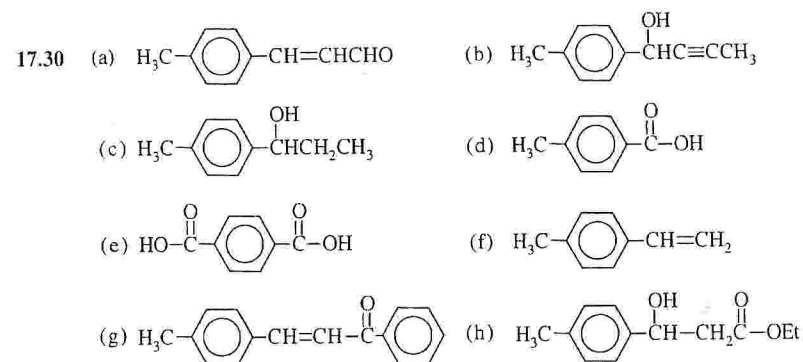
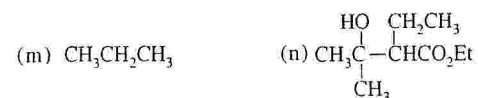
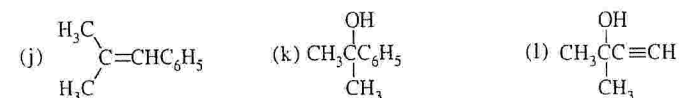
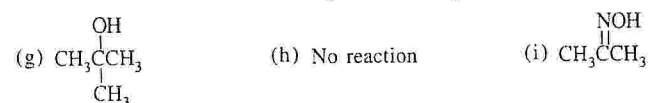
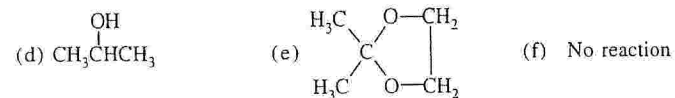
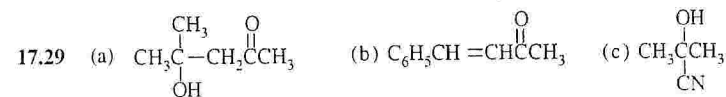
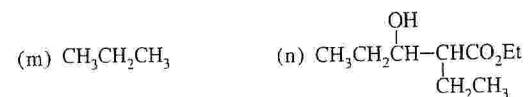
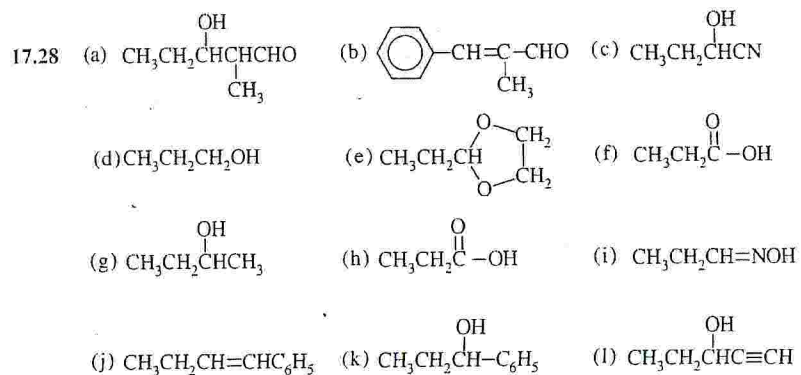
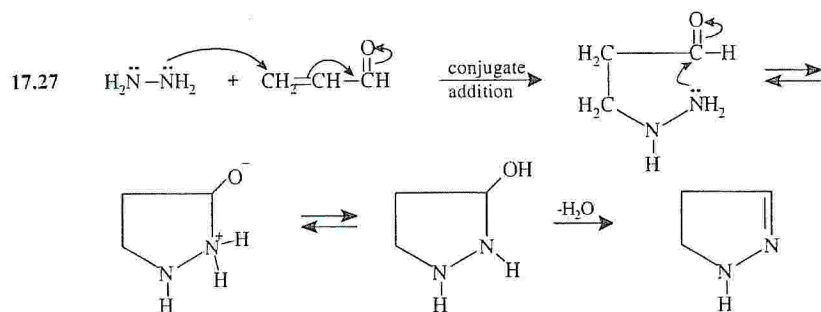
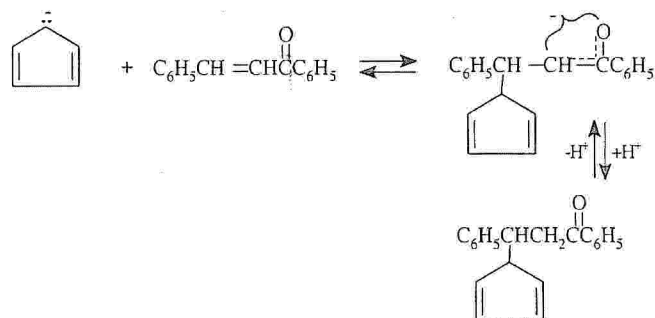
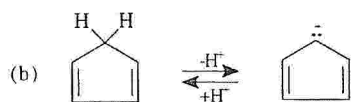


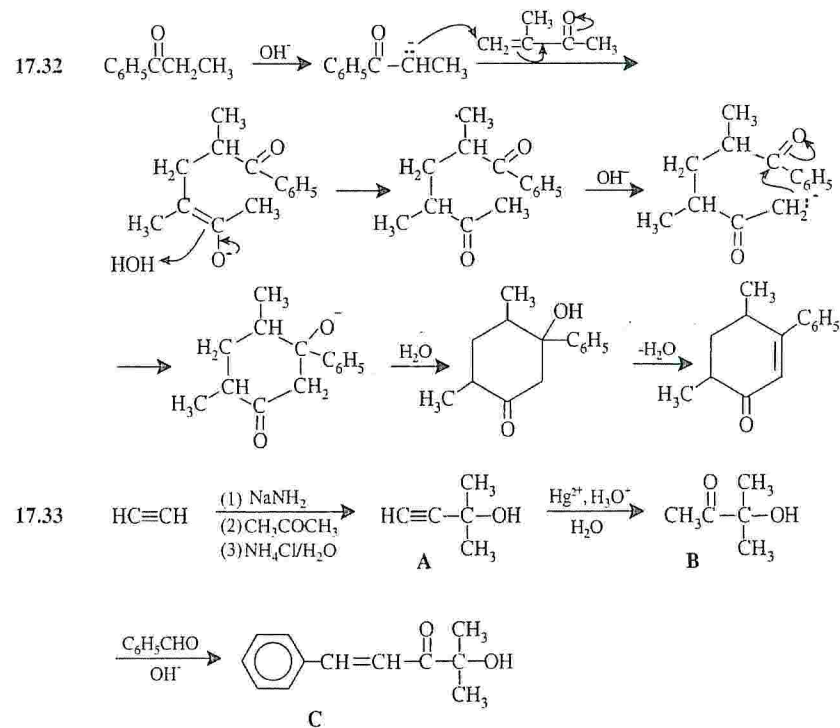
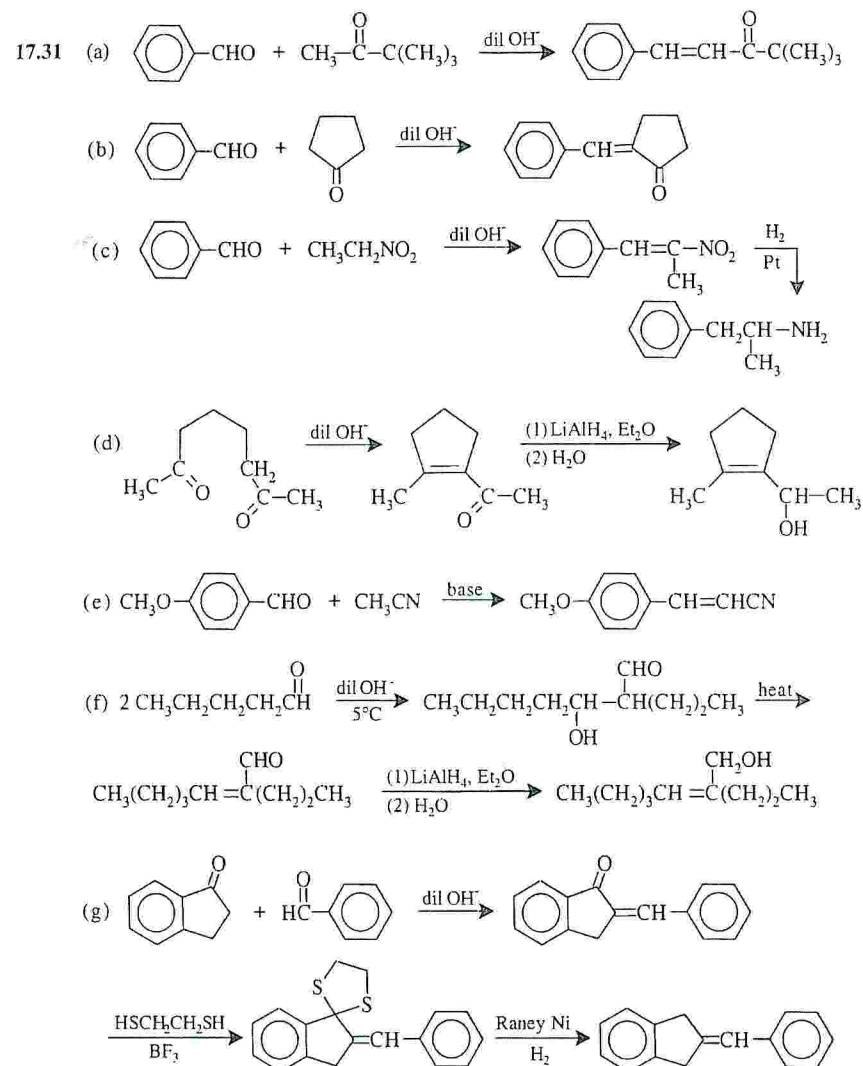




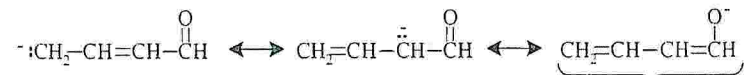
(b) 2-Methyl-1,3-cyclohexanedione is more acidic because its enolate ion is stabilized by an additional resonance structure.



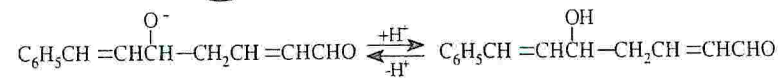
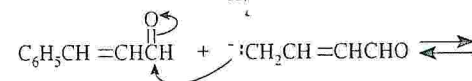
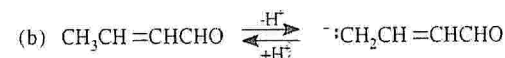


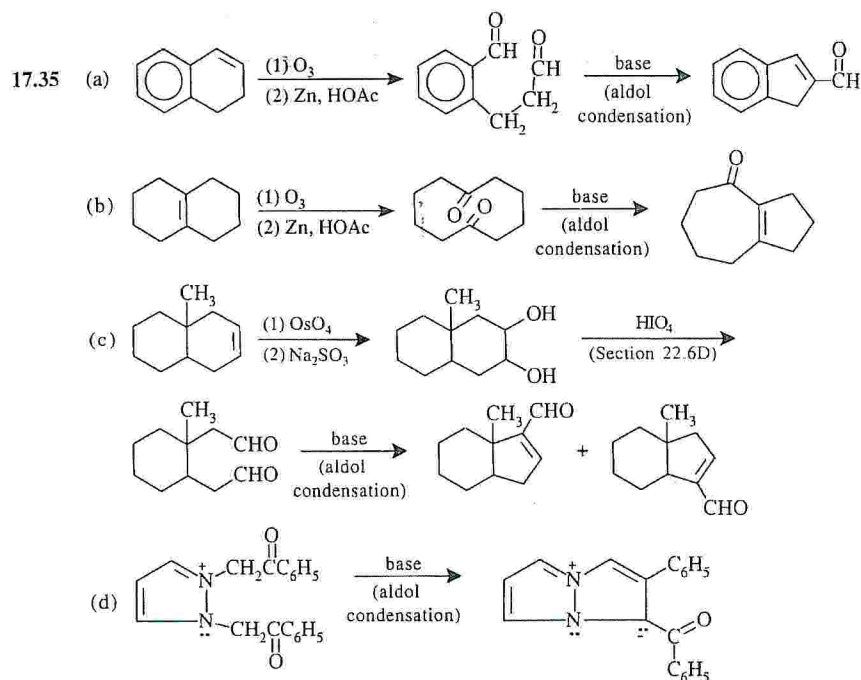


17.34 (a) The conjugate base is a hybrid of the following structures:



This structure is especially stable because the negative charge is on the oxygen atom.

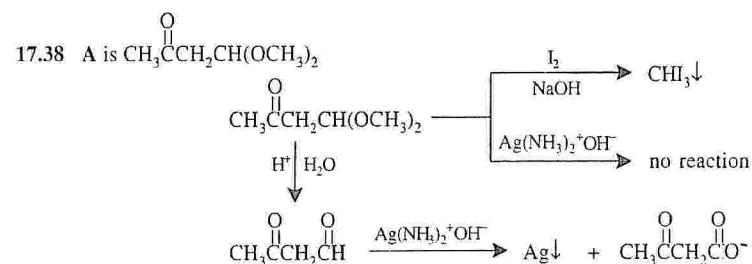
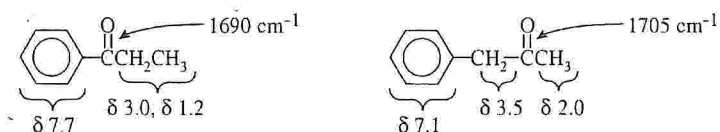




17.36 (a) In simple addition, the carbonyl peak ( $1665\text{--}1780\text{-cm}^{-1}$  region) does not appear in the product; in conjugate addition it does.

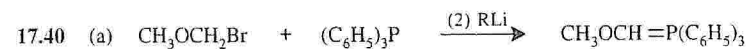
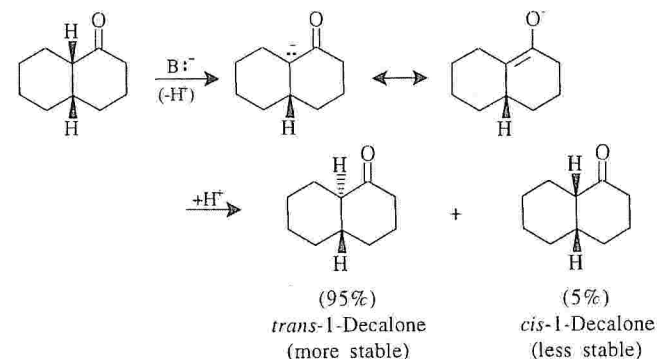
(b) As the reaction takes place, the long-wavelength absorption arising from the conjugated system should disappear. One could follow the rate of the reaction by following the rate at which this absorption peak disappears.

17.37 (a) Compound U is ethyl phenyl ketone: (b) Compound V is benzyl methyl ketone:

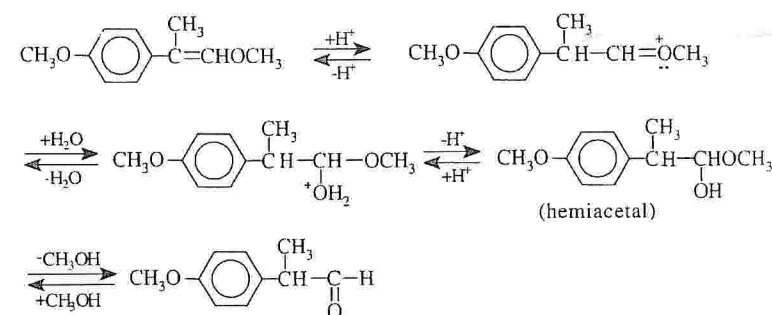


(a) Singlet  $\delta$  2.1 (b) Doublet  $\delta$  2.6 (c) Triplet  $\delta$  4.7 (d) Singlet  $\delta$  3.2

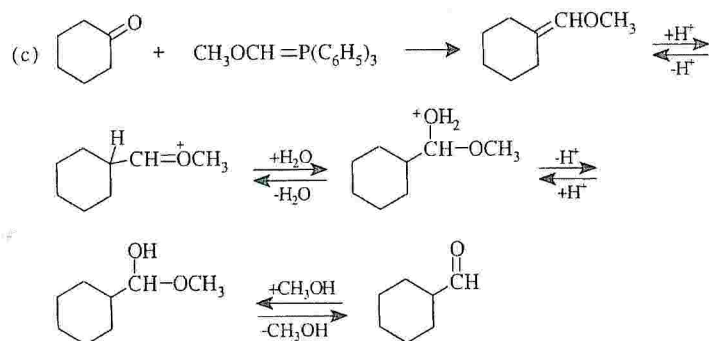
17.39 Abstraction of an  $\alpha$  hydrogen at the ring junction yields an enolate ion that can then accept a proton to form either *trans*-1-decalone or *cis*-1-decalone. Since *trans*-1-decalone is more stable, it predominates at equilibrium.



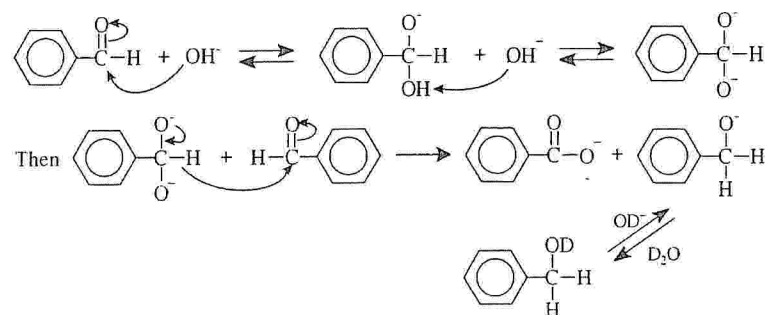
(b) Hydrolysis of the ether yields a hemiacetal that then goes on to form an aldehyde.







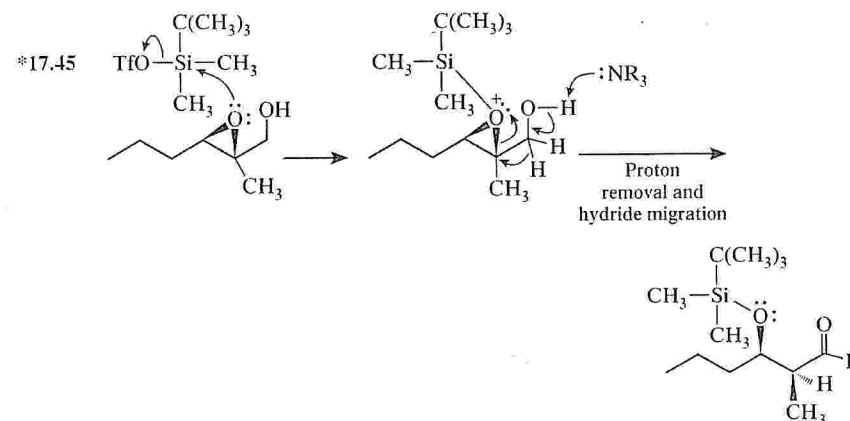
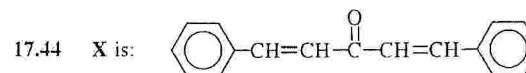
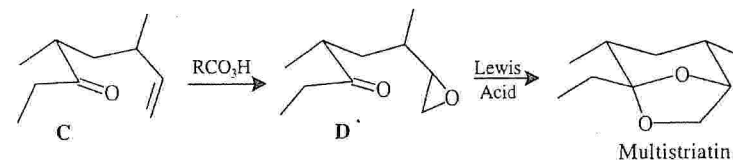
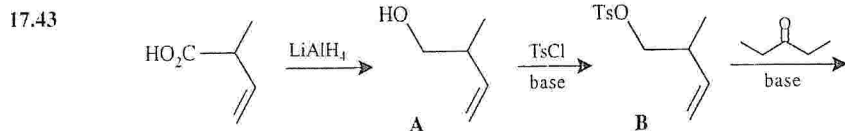
- 17.41 (a) The hydrogen atom that is added to the aldehyde carbon atom in the reduction must come from the other aldehyde rather than from the solvent. It must be transferred as a hydride ion and directly from molecule to molecule, since if it were ever a free species it would react immediately with the solvent. A possible mechanism is the following:



(b) Although an aldol reaction occurs initially, the aldol reaction is reversible. The Cannizzaro reaction, though slower, is irreversible. Eventually, all the product is in the form of the alcohol and the carboxylate ion.

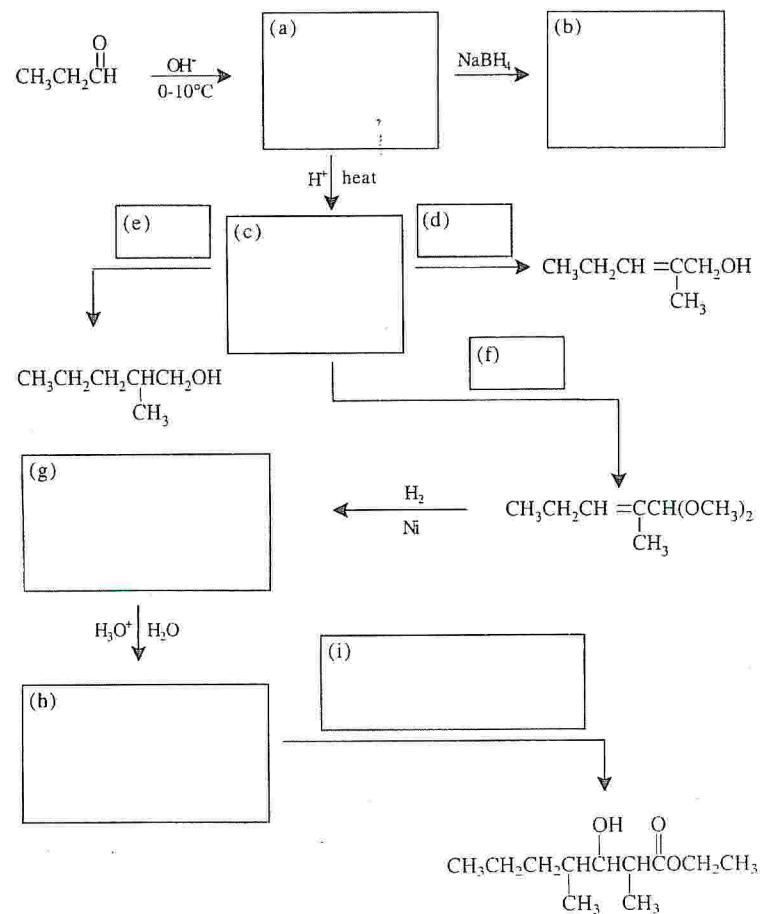
- 17.42 This difference in behavior indicates that, for acetaldehyde, the capture of a proton from the solvent (the reverse of the reaction by which the enolate ion is formed) occurs much more slowly than the attack by the enolate ion on another molecule.

When acetone is used, the equilibrium for the formation of the enolate ion is unfavorable, but more importantly, enolate attack on another acetone molecule is disfavored due to steric hindrance. Here proton capture (actually deuteron capture) competes very well with the aldol reaction.

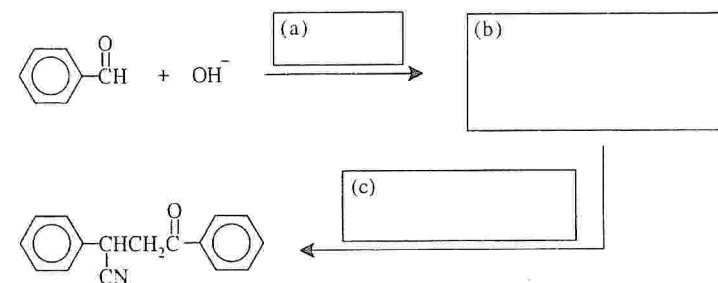


## QUIZ

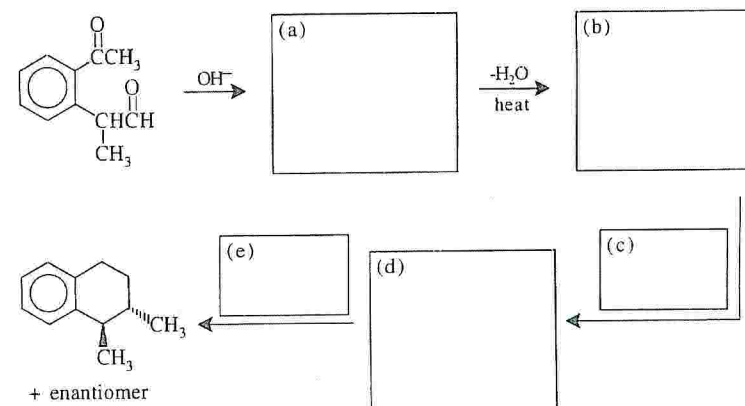
17.1 Supply formulas for the missing reagents and intermediates in the following synthesis.



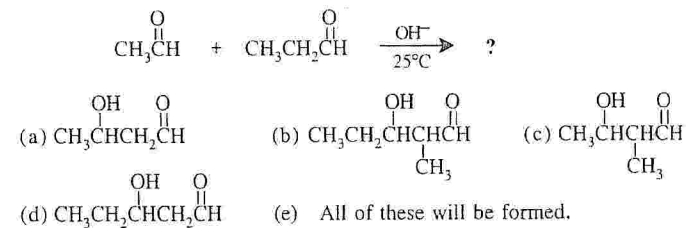
17.2 Supply formulas for the missing reagents and intermediates in the following synthesis.



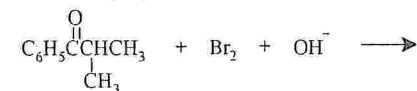
17.3 Supply formulas for the missing reagents and intermediates in the following synthesis.



17.4 Which would be formed in the following reaction?



17.5 What would be the major product of the following reaction?



- (a)  $\text{C}_6\text{H}_5\text{C}(\text{O})\text{CBrCH}_3$       (b)  $\text{C}_6\text{H}_5\text{C}(\text{O})\text{CH}(\text{CH}_3)\text{CH}_2\text{Br}$       (c)  $\text{C}_6\text{H}_5\text{C}(\text{O})\text{CH}(\text{CH}_3)\text{CH}_2\text{OH}$
- (d)  $\text{C}_6\text{H}_5\text{CBr}_2\text{CH}(\text{CH}_3)\text{CH}_3$       (e) None of these

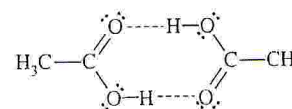
## 18

CARBOXYLIC ACIDS AND THEIR  
DERIVATIVES: NUCLEOPHILIC ADDITION-  
ELIMINATION AT THE ACYL CARBON

## SOLUTIONS TO PROBLEMS

- 18.1 (a) 2-Methylbutanoic acid  
(b) 3-Pentenoic acid  
(c) Sodium 4-bromobutanoate  
(d) 5-Phenylpentanoic acid  
(e) 3-Methyl-3-pentenoic acid

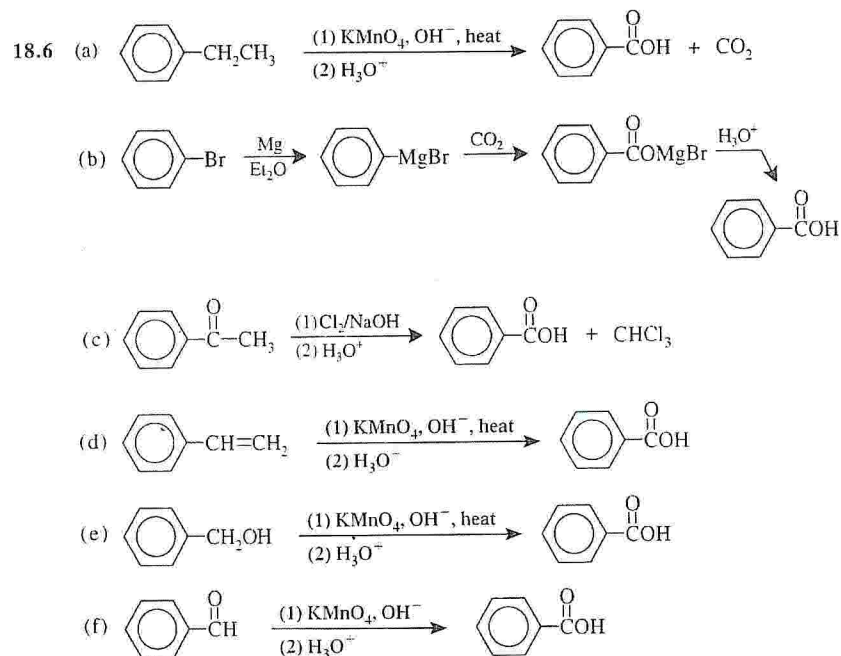
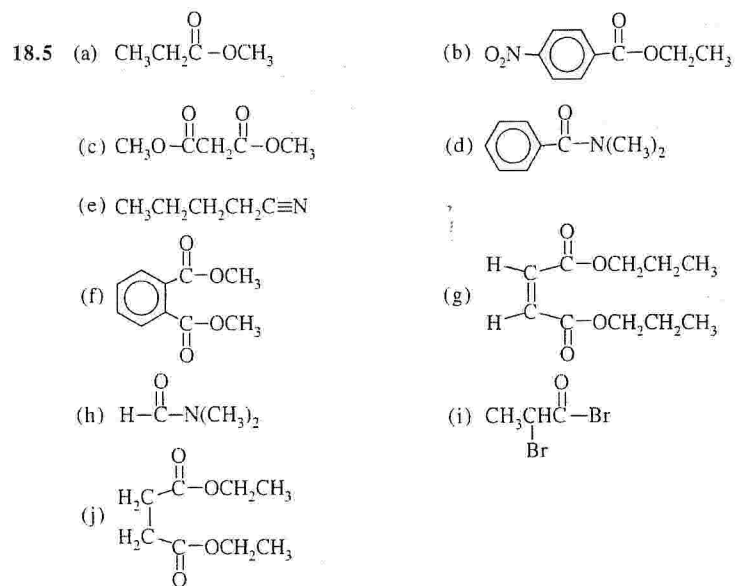
- 18.2 Acetic acid, in the absence of solvating molecules, exists as a dimer owing to the formation of two intermolecular hydrogen bonds:



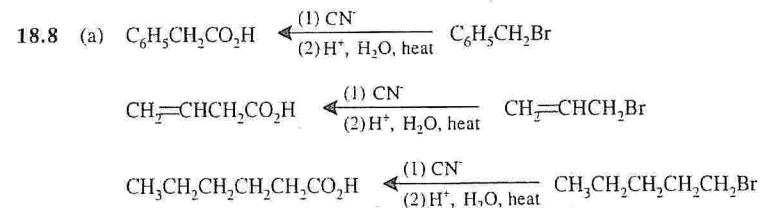
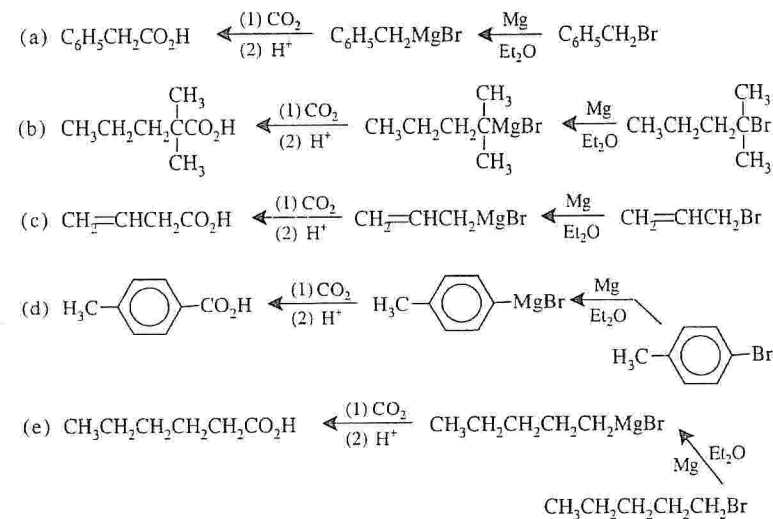
At temperatures much above the boiling point, the dimer dissociates into the individual molecules.

- 18.3 (a)  $\text{CH}_2\text{FCO}_2\text{H}$  (F- is more electronegative than H-)  
(b)  $\text{CH}_2\text{FCO}_2\text{H}$  (F- is more electronegative than Cl-)  
(c)  $\text{CH}_2\text{ClCO}_2\text{H}$  (Cl- is more electronegative than Br-)  
(d)  $\text{CH}_3\text{CHFCH}_2\text{CO}_2\text{H}$  (F- is closer to  $-\text{CO}_2\text{H}$ )  
(e)  $\text{CH}_3\text{CH}_2\text{CHFCO}_2\text{H}$  (F- is closer to  $-\text{CO}_2\text{H}$ )  
(f)  $(\text{CH}_3)_3\text{N}^+-\text{C}_6\text{H}_4-\text{CO}_2\text{H}$  [ $(\text{CH}_3)_3\text{N}^+$  is more electronegative than H-]  
(g)  $\text{CF}_3-\text{C}_6\text{H}_4-\text{CO}_2\text{H}$  ( $\text{CF}_3$ - is more electronegative than  $\text{CH}_3$ -)

- 18.4 (a) The carboxyl group is an electron-withdrawing group; thus, in a dicarboxylic acid such as those in Table 18.3, one carboxyl group increases the acidity of the other.  
(b) As the distance between the carboxyl groups increases the acid-strengthening, inductive effect decreases.

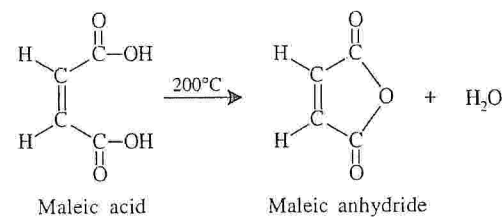


18.7 These syntheses are easy to see if we work backward.



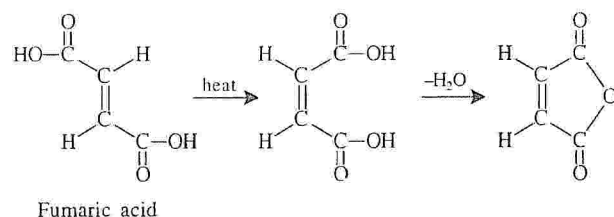
(b) A nitrile synthesis. Preparation of a Grignard reagent from  $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$  would not be possible because of the presence of the acidic hydroxyl group.

18.9 Since maleic acid is a cis dicarboxylic acid, dehydration occurs readily:

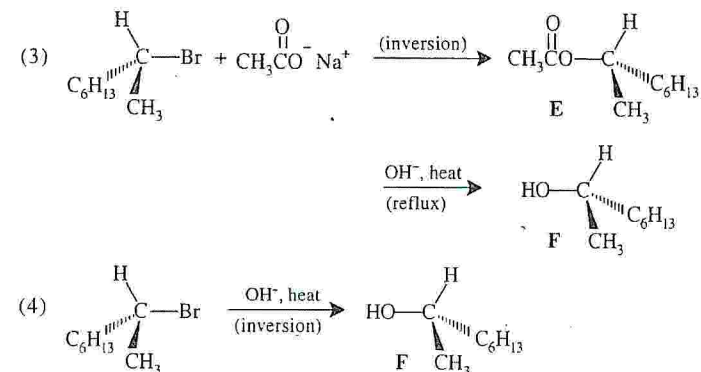
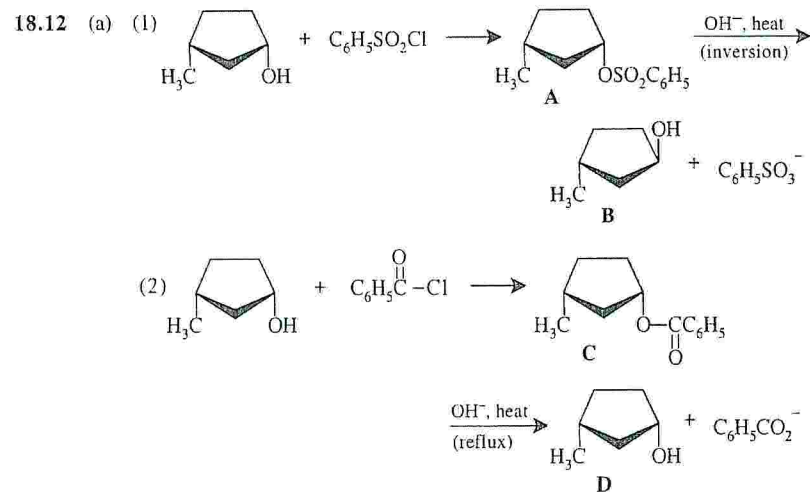
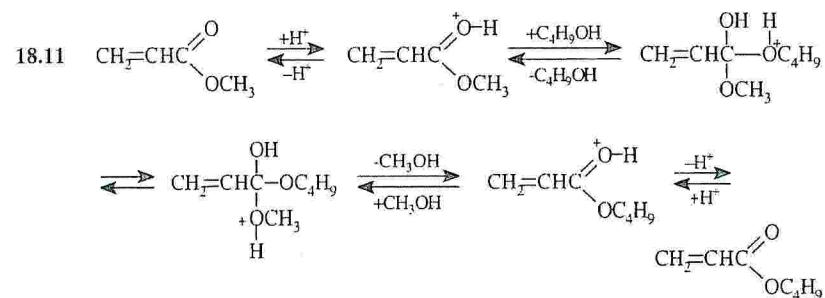




Being a trans dicarboxylic acid, fumaric acid must undergo isomerization to maleic acid first. This isomerization requires a higher temperature.



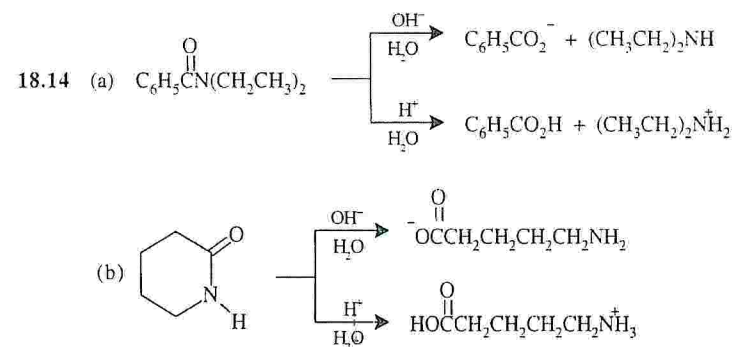
**18.10** The labeled oxygen atom should appear in the carboxyl group of the acid. (Follow the reverse steps of the mechanism in Section 18.7A of the text using  $\text{H}_2^{18}\text{O}$ .)

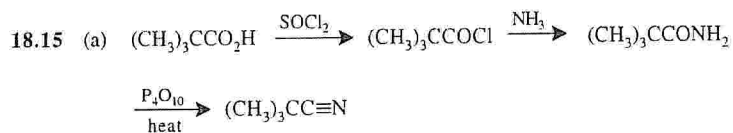
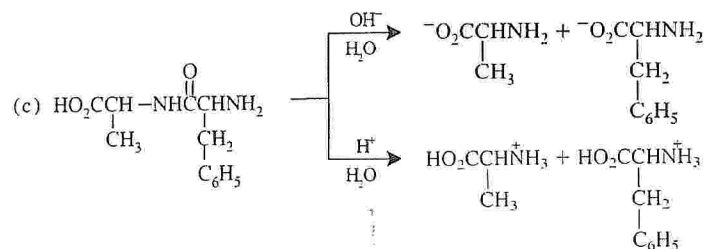


(b) Method (3) should give a higher yield of F than method (4). Since the hydroxide ion is a strong base and since the alkyl halide is secondary, method (4) is likely to be accompanied by considerable elimination. Method (3), on the other hand, employs a weaker base, acetate ion, in the  $\text{S}_{\text{N}}2$  step and is less likely to be complicated by elimination. Hydrolysis of the ester E that results should also proceed in high yield.

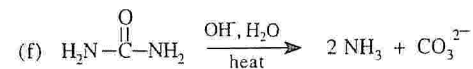
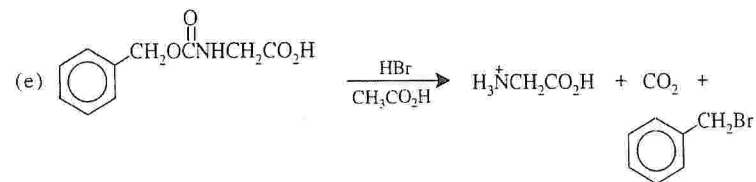
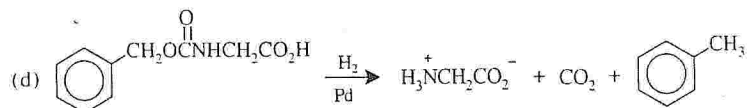
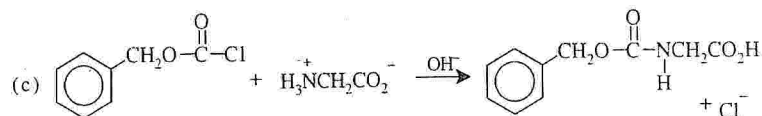
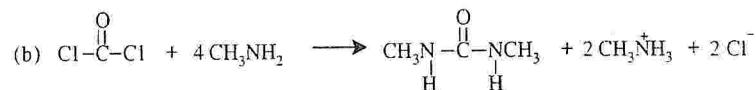
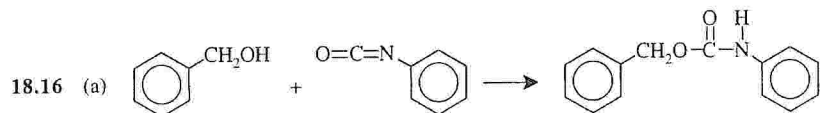
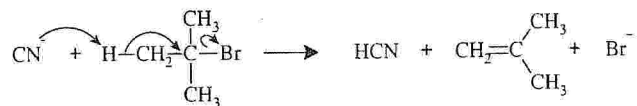
**18.13** (a) Steric hindrance presented by the di-ortho methyl groups of methyl mesitoate prevents formation of the tetrahedral intermediate that must accompany attack at the acyl carbon.

(b) Carry out hydrolysis with labeled  $^{18}\text{OH}^-$  in labeled  $\text{H}_2^{18}\text{O}$ . The label should appear in the methanol.

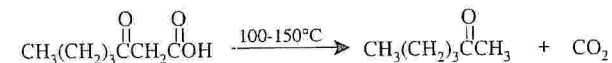




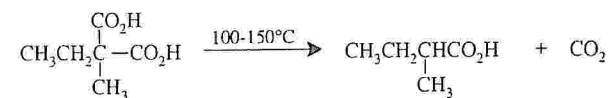
(b) An elimination reaction would take place because  $\text{CN}^-$  is a strong base.



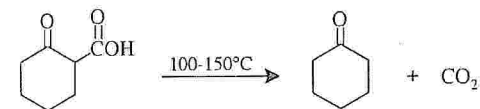
18.17 (a) By decarboxylation of a  $\beta$ -keto acid:



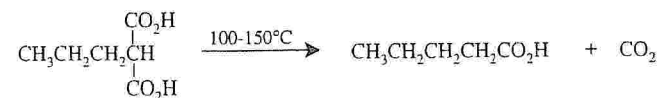
(b) By decarboxylation of a substituted malonic acid:



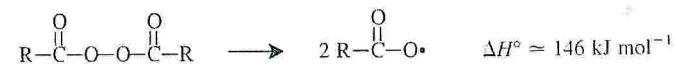
(c) By decarboxylation of a  $\beta$ -keto acid:



(d) By decarboxylation of a substituted malonic acid:



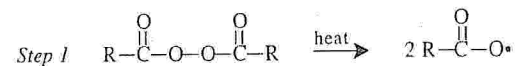
18.18 (a) The oxygen-oxygen bond of the diacyl peroxide has a low homolytic bond dissociation energy ( $\Delta H^\circ \approx 146 \text{ kJ mol}^{-1}$ ). This allows the following reaction to occur at a moderate temperature.



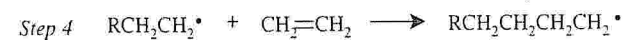
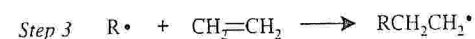
(b) By decarboxylation of the carboxylate radical produced in part (a).



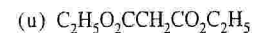
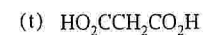
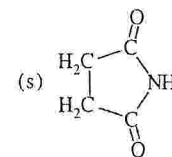
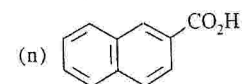
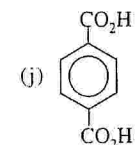
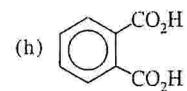
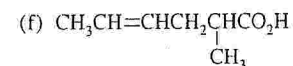
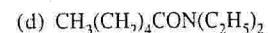
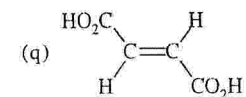
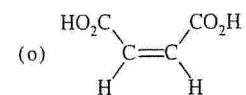
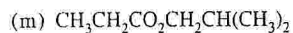
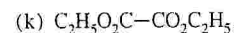
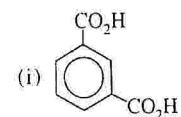
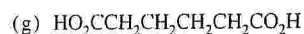
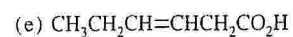
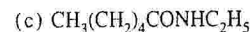
## (c) Chain Initiation



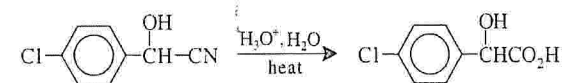
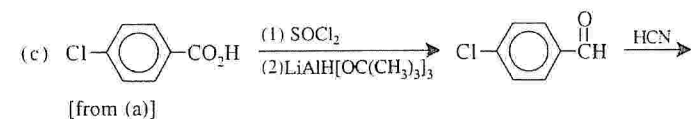
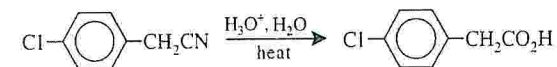
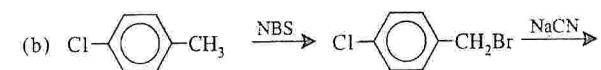
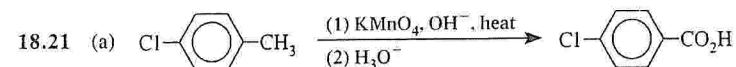
## Chain Propagation

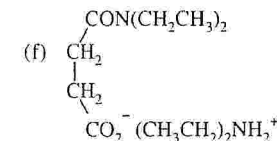
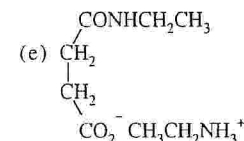
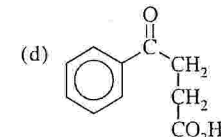
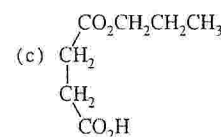
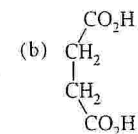
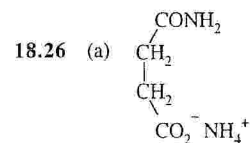
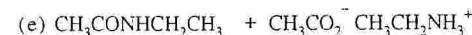
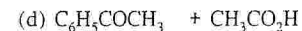
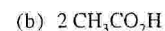
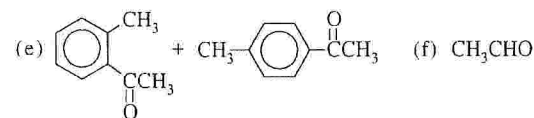
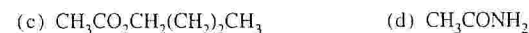
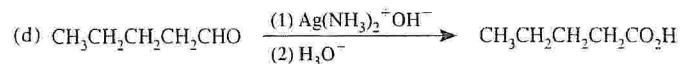
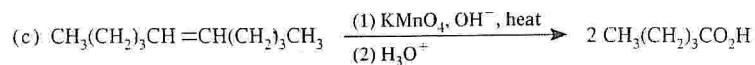
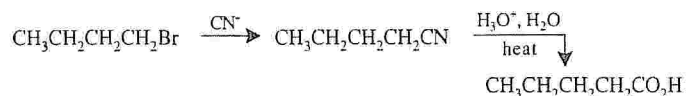
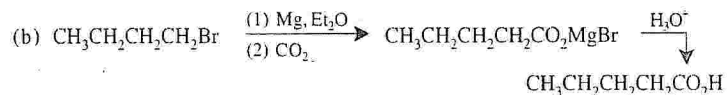
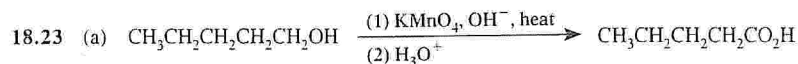
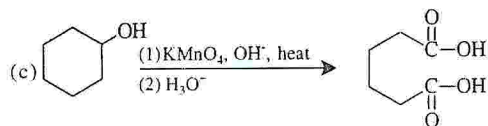
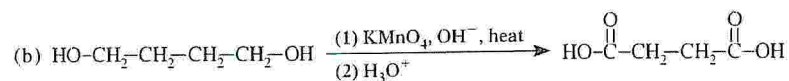
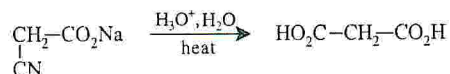
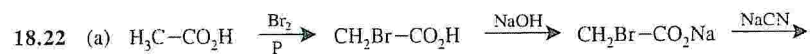
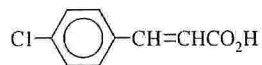
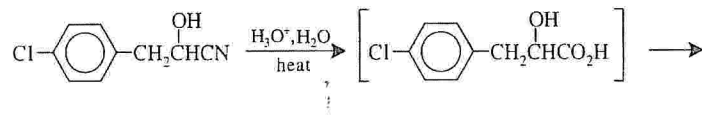
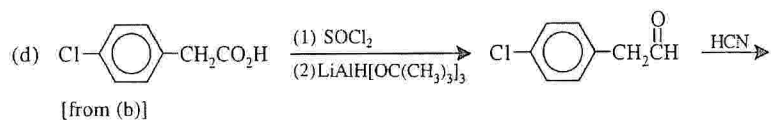


Step 3, 4, 3, 4, and so on.



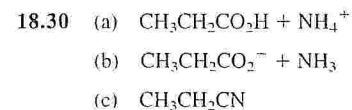
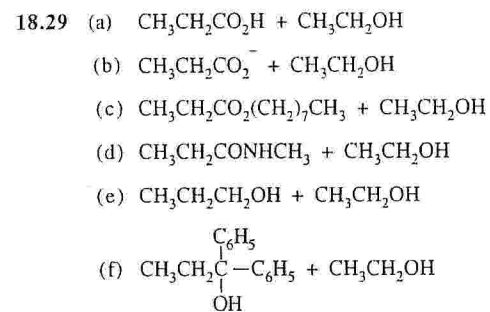
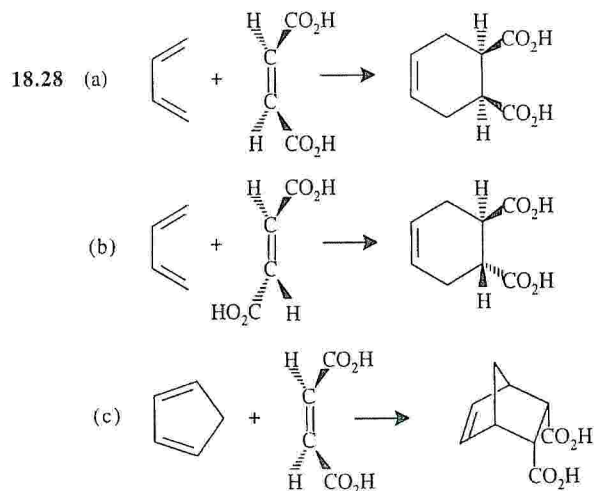
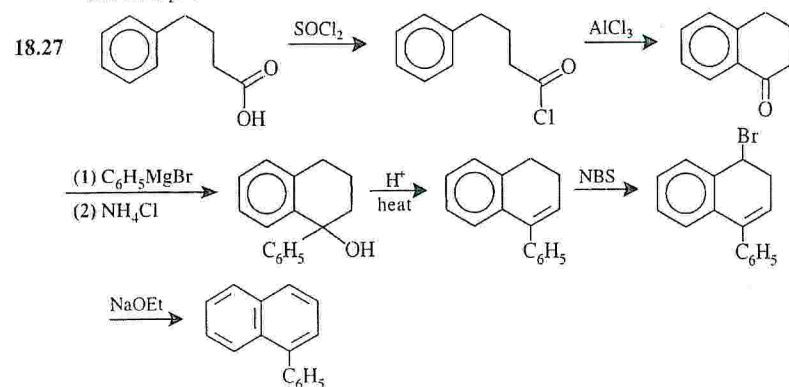
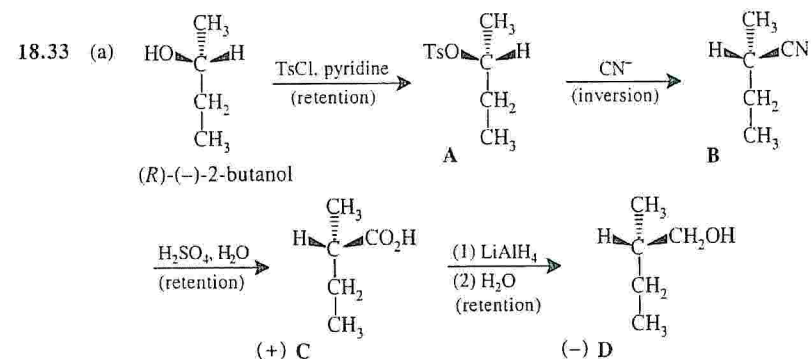
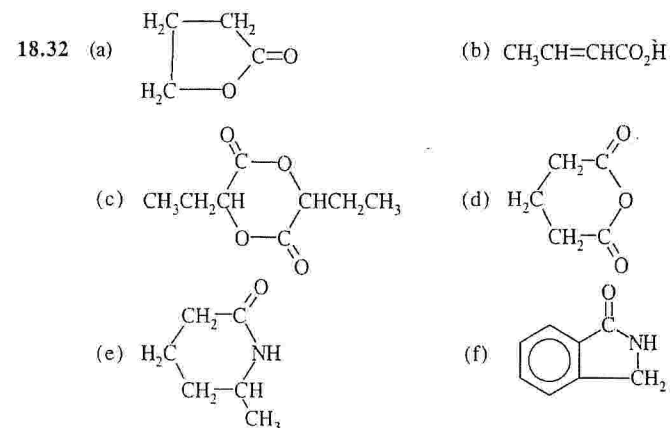
- 18.20 (a) Benzoic acid  
 (b) Benzoyl chloride  
 (c) Benzamide  
 (d) Benzoic anhydride  
 (e) Benzyl benzoate  
 (f) Phenyl benzoate  
 (g) Isopropyl acetate or 1-methylethyl ethanoate  
 (h) *N,N*-Dimethylacetamide or *N,N*-dimethylethanamide  
 (i) Acetonitrile or ethanenitrile

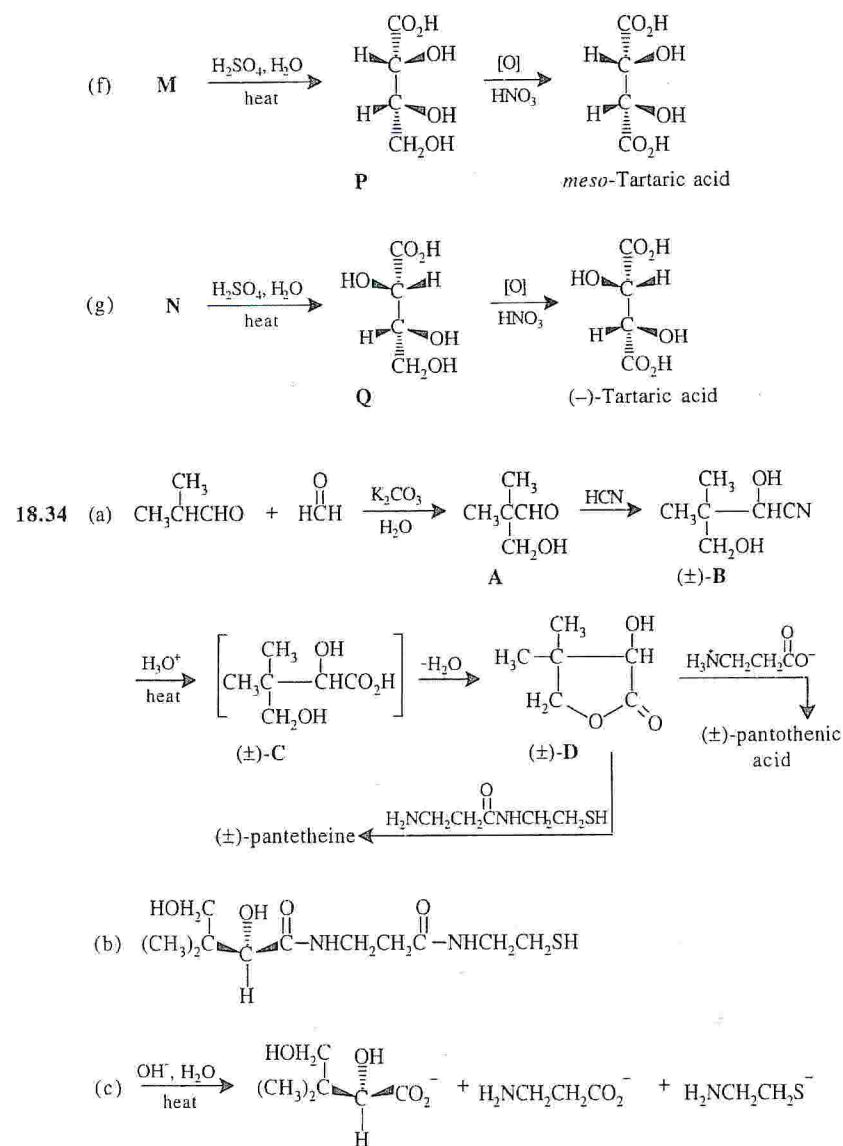
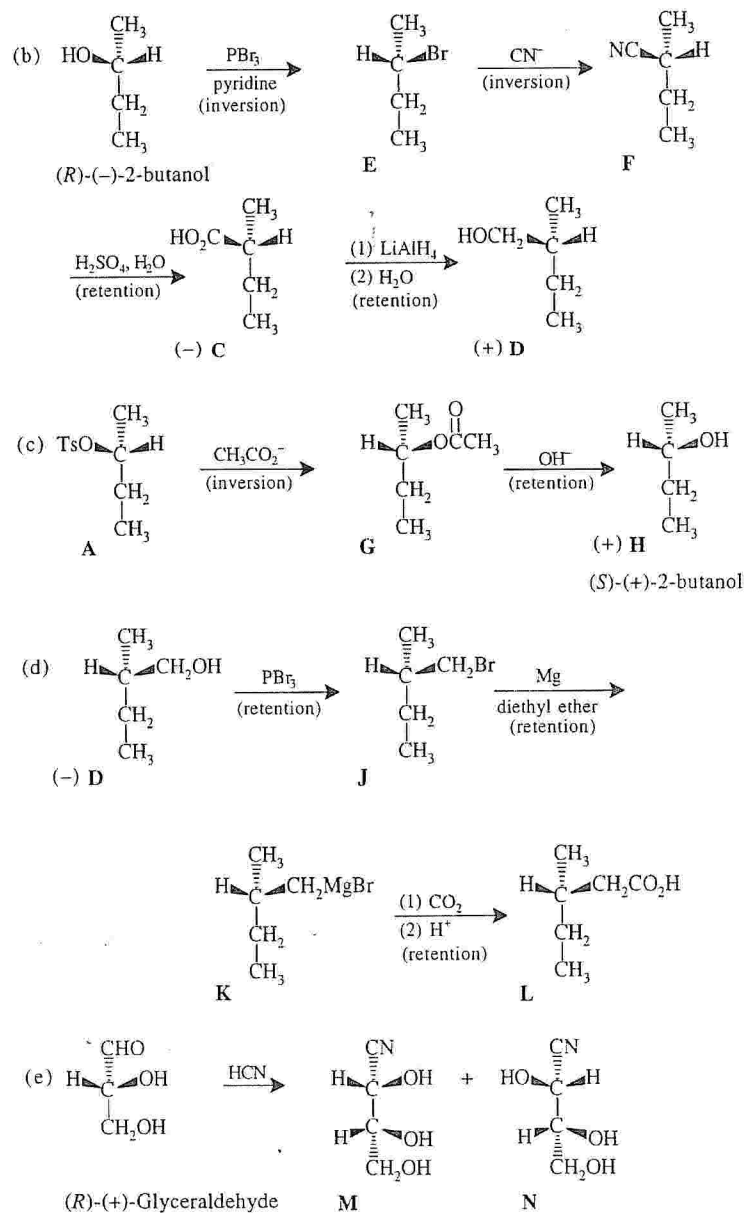


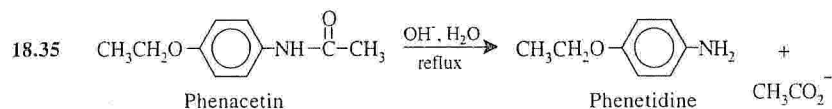




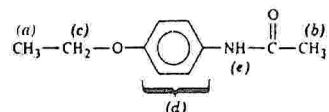
See text, p. 677.

18.31 See the mechanisms in Section 18.8F, where  $\text{R} = \text{CH}_2\text{CH}_3$  for propanamide.

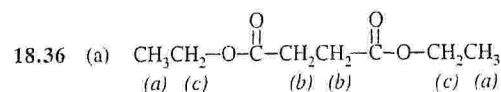




An interpretation of the  $^1\text{H}$  NMR spectral data for phenacetin is as follows:

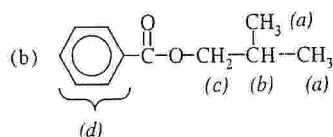


- (a) triplet  $\delta$  1.4  
 (b) singlet  $\delta$  2.1  
 (c) quartet  $\delta$  3.95  
 (d) multiplet  $\delta$  6.8-7.4  
 (e) broad singlet  $\delta$  9.0



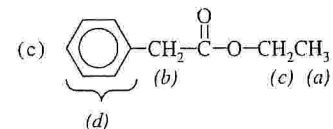
Interpretation:

- (a) Triplet  $\delta$  1.2 (6H)  $2 - \text{C}(=\text{O})-\text{O}-$ ,  $1740 \text{ cm}^{-1}$  (ester)  
 (b) Singlet  $\delta$  2.5 (4H)  
 (c) Quartet  $\delta$  4.1 (4H)



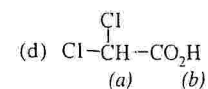
Interpretation:

- (a) Doublet  $\delta$  1.0 (6H)  $-\text{C}(=\text{O})-\text{O}-$ ,  $1720 \text{ cm}^{-1}$  (ester)  
 (b) Multiplet  $\delta$  2.1 (1H)  
 (c) Doublet  $\delta$  4.1 (2H)  
 (d) Multiplet  $\delta$  7.8 (5H)



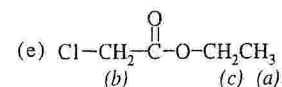
Interpretation:

- (a) Triplet  $\delta$  1.2 (3H)  $-\text{C}(=\text{O})-\text{O}-$ ,  $1740 \text{ cm}^{-1}$  (ester)  
 (b) Singlet  $\delta$  3.5 (2H)  
 (c) Quartet  $\delta$  4.1 (2H)  
 (d) Multiplet  $\delta$  7.3 (5H)



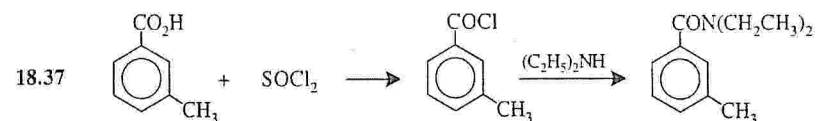
Interpretation:

- $-\text{OH}$ ,  $2500-2700 \text{ cm}^{-1}$   
 (a) Singlet  $\delta$  6.0  $-\text{C}(=\text{O})-\text{O}-$ ,  $1705 \text{ cm}^{-1}$  (acid)  
 (b) Singlet  $\delta$  11.7

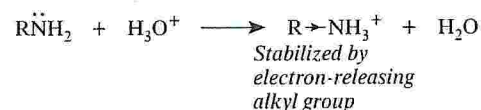


Interpretation:

- (a) Triplet  $\delta$  1.3  $-\text{C}(=\text{O})-\text{O}-$ ,  $1745 \text{ cm}^{-1}$  (ester)  
 (b) Singlet  $\delta$  4.0  
 (c) Quartet  $\delta$  4.2



- 18.38** Alkyl groups are electron releasing; they help disperse the positive charge of an alkylammonium salt and thereby help to stabilize it.

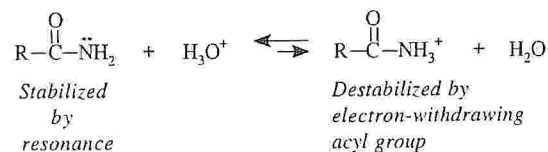


Consequently, alkylamines are somewhat stronger bases than ammonia.

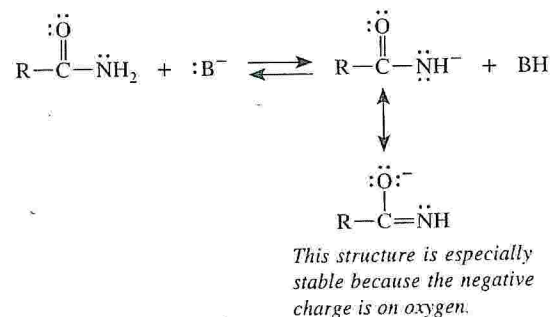
Amides, on the other hand, have acyl groups,  $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-$ , attached to nitrogen, and acyl groups are electron withdrawing. They are especially electron withdrawing because of resonance contributions of the kind shown here.



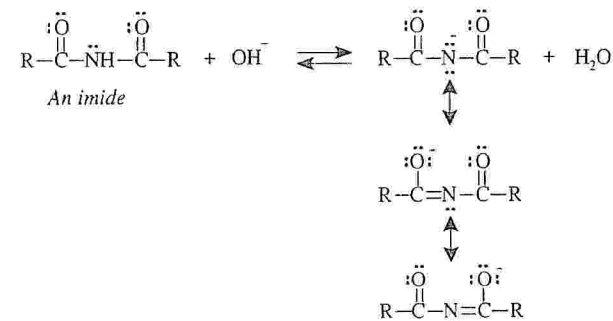
This kind of resonance also *stabilizes* the amide. The tendency of the acyl group to be electron withdrawing, however, *destabilizes* the conjugate acid of an amide, and reactions of such as the following do not take place to an appreciable extent.



- 18.39** (a) The conjugate base of an amide is stabilized by resonance.



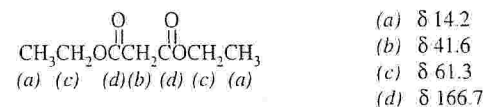
- (b) The conjugate base of an imide is stabilized by an additional resonance structure,



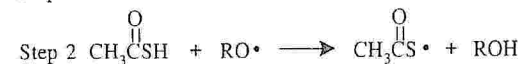
- 18.40** That compound X does not dissolve in aqueous sodium bicarbonate indicates that X is not a carboxylic acid. That X has an IR absorption peak at  $1740\text{ cm}^{-1}$  indicates the presence of a carbonyl group, probably that of an ester (Table 18.5). That the molecular formula of X ( $\text{C}_7\text{H}_{12}\text{O}_4$ ) contains four oxygen atoms suggests that X is a diester.

The  $^{13}\text{C}$  spectrum shows only four signals indicating a high degree of symmetry for X. The single signal at  $\delta 166.7$  is that of an ester carbonyl carbon, indicating that both ester groups of X are equivalent.

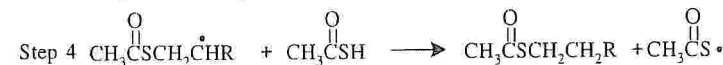
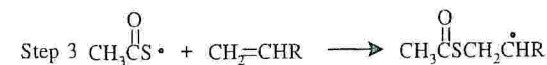
Putting these observations together with the information gathered from DEPT  $^{13}\text{C}$  spectra and the molecular formula leads us to the conclusion that X is diethyl malonate. The assignments are



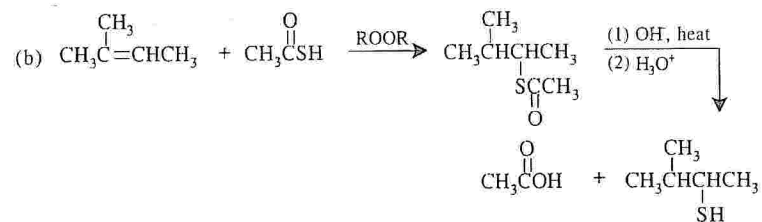
- 18.41** (a) *Chain Initiation*



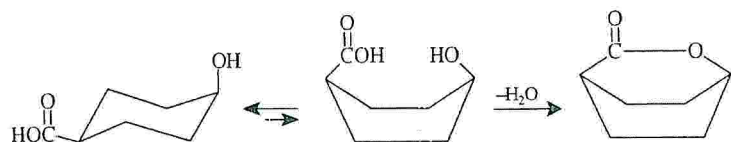
*Chain Propagation*





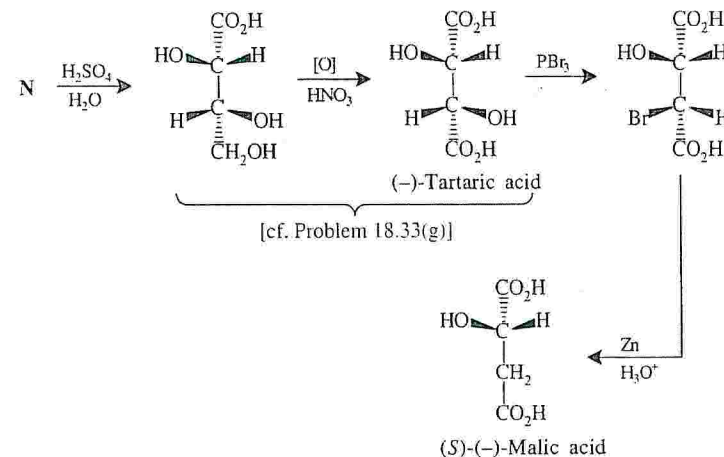
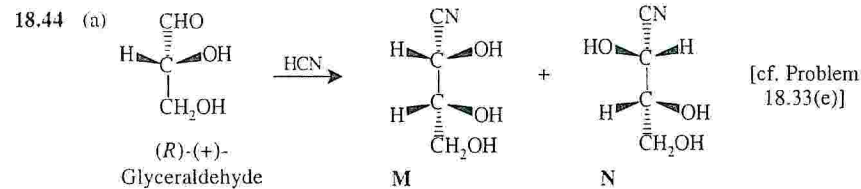
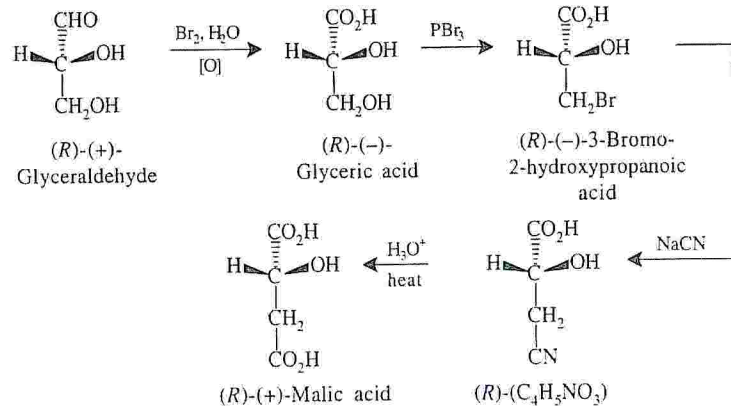


18.42 *cis*-4-Hydroxycyclohexanecarboxylic acid can assume a boat conformation that permits lactone formation.

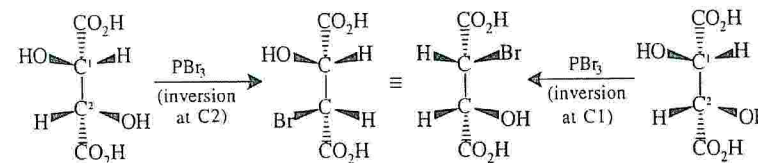


Neither of the chair conformations nor the boat form of *trans*-4-hydroxycyclohexanecarboxylic acid places the -OH group and the -CO<sub>2</sub>H group close enough together to permit lactonization.

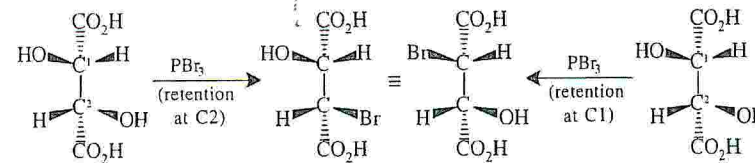
18.43



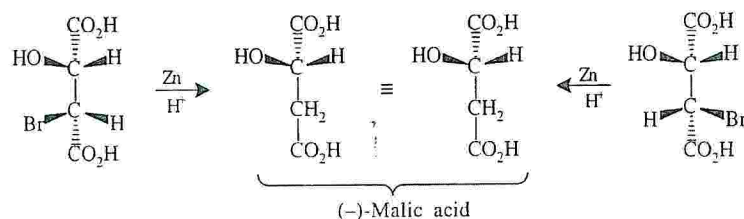
(b) Replacement of either alcoholic -OH by a reaction that proceeds with inversion produces the same stereoisomer.



(c) Two. The stereoisomer given in (b) and the one given next, below.



(d) It would have made no difference because treating either isomer (or both together) with zinc and acid produces (–) malic acid.



18.45 (a)  $\text{CH}_3\text{O}_2\text{C}-\text{C}\equiv\text{C}-\text{CO}_2\text{CH}_3$ . This is a Diels-Alder reaction.

(b)  $\text{H}_2$ , Pd. The disubstituted double bond is less hindered than the tetrasubstituted double bond and hence is more reactive.

(c)  $\text{CH}_2=\text{CH}-\text{CH}=\text{CH}_2$ . Another Diels-Alder reaction.

(d)  $\text{LiAlH}_4$

(e)  $\text{CH}_3-\text{SO}_2-\text{Cl}$  and pyridine

(f)  $\text{CH}_3\text{CH}_2\text{S}^-$

(g)  $\text{OsO}_4$

(h) Raney Ni

(i) Base. This is an aldol condensation.

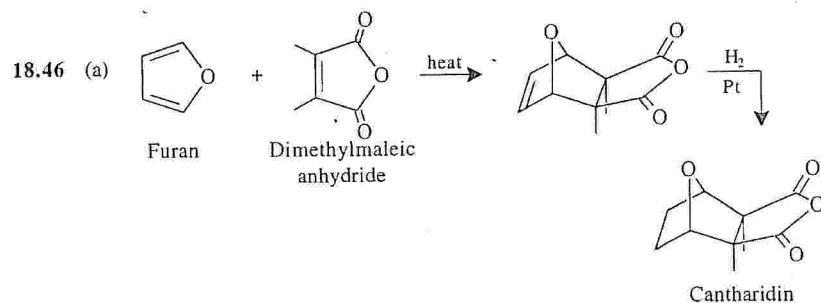
(j)  $\text{C}_6\text{H}_5\text{Li}$  (or  $\text{C}_6\text{H}_5\text{MgBr}$ ) followed by  $\text{H}_3\text{O}^+$

(k)  $\text{H}_3\text{O}^+$ . This is an acid-catalyzed rearrangement of an allylic alcohol.

(l)  $\text{CH}_3\text{COCl}$ , pyridine

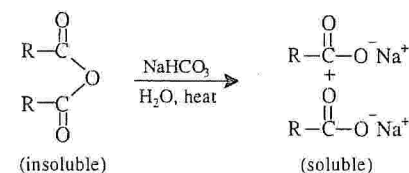
(m)  $\text{O}_3$ , followed by oxidation

(n) Heat



(b) Cantharidin apparently undergoes dehydrogenation to the Diels-Alder adduct shown here, and then the adduct spontaneously decomposes through a reverse Diels-Alder reaction to furan and dimethylmaleic anhydride. These results suggest that the attempted Diels-Alder synthesis fails because the position of equilibrium favors reactants rather than products.

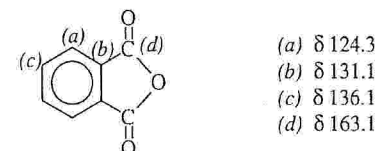
18.47 The very low hydrogen content of the molecular formula of Y ( $\text{C}_8\text{H}_4\text{O}_3$ ) indicates that Y is highly unsaturated. That Y dissolves slowly in warm aqueous  $\text{NaHCO}_3$  suggests that Y is a carboxylic acid anhydride that hydrolyzes and dissolves because it forms a carboxylate salt:



The infrared absorption peaks at  $1779$  and  $1854\text{ cm}^{-1}$  are consistent with those of an aromatic carboxylic anhydride (Table 18.5).

That only four signals appear in the  $^{13}\text{C}$  spectrum of Y indicates a high degree of symmetry for Y. Three of the signals occur in the aromatic region ( $\delta\ 120\text{--}\delta\ 140$ ) and one signal is downfield ( $\delta\ 163.1$ ).

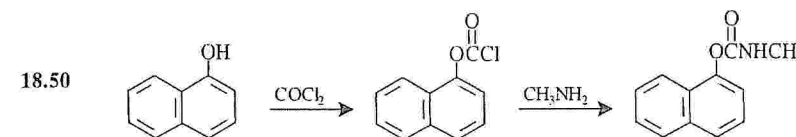
These signals and the information from the DEPT  $^{13}\text{C}$  NMR spectra lead us to conclude that Y is phthalic anhydride. The assignments are

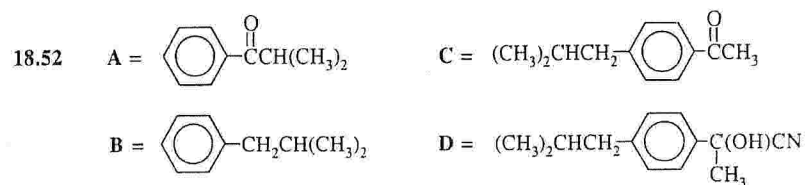
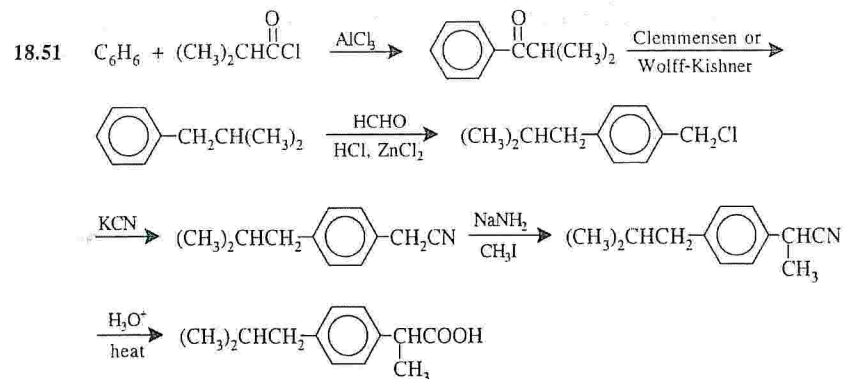


Z is phthalic acid and AA is ethyl hydrogen phthalate.

18.48 (a) Ethyl acetate (b) Acetic anhydride (c) *N*-Ethylacetamide.

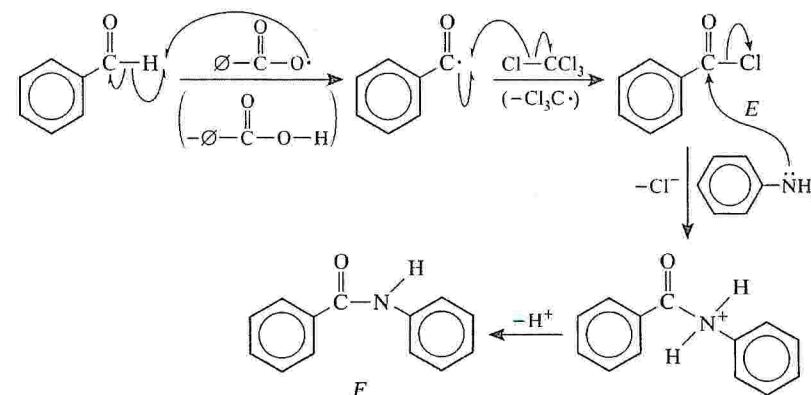
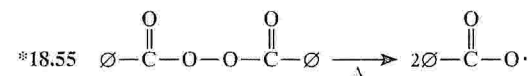
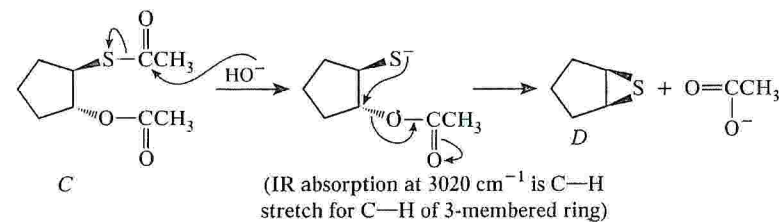
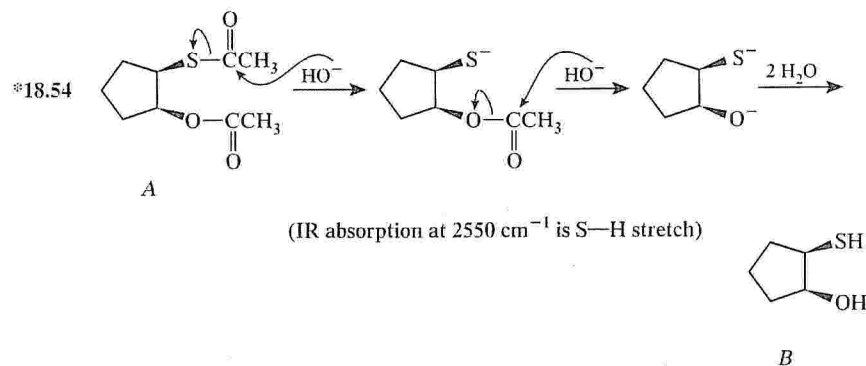
18.49 In the first instance, nucleophilic attack by the amine occurs preferentially at the less hindered carbon of the formyl group. (Recall that aldehydes are more reactive than ketones toward nucleophiles for the same reason.) In the second case,  $\text{CF}_3\text{CO}_2^-$  is a better leaving group than  $\text{CH}_3\text{CO}_2^-$  since the former is the conjugate base of the stronger acid.





In the last step,  $\text{HI}/\text{red P}$  accomplishes both the reduction of  $-\text{OH}$  to  $-\text{H}$  and the hydrolysis of the nitrile function.

- 18.53 (a) The signal at  $\delta$  193.8 is consistent with the carbonyl carbon of an aldehyde and shows that the PCC reaction produced cinnamaldehyde.
- (b) The signal at  $\delta$  164.5 is consistent with the carbonyl carbon of a carboxylic acid, and suggests that the oxidation with  $\text{K}_2\text{Cr}_2\text{O}_7$  in sulfuric acid produced cinnamic acid.



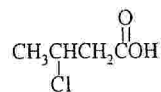
## QUIZ

- 18.1 Which of the following would be the strongest acid?
- (a) Benzoic acid (b) 4-Nitrobenzoic acid (c) 4-Methylbenzoic acid  
(d) 4-Methoxybenzoic acid (e) 4-Ethylbenzoic acid
- 18.2 Which of the following would yield (S)-2-butanol?
- (a) (R)-2-Bromobutane +  $\text{CH}_3\text{CO}_2^-\text{Na}^+ \xrightarrow[\text{heat}]{\text{OH}^-, \text{H}_2\text{O}}$  product  
(b) (R)-2-Bromobutane  $\xrightarrow[\text{heat}]{\text{OH}^-, \text{H}_2\text{O}}$   
(c) (S)-2-Butyl acetate  $\xrightarrow[\text{heat}]{\text{OH}^-, \text{H}_2\text{O}}$   
(d) All of the above  
(e) None of the above

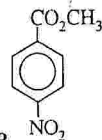
18.3 Which reagent would serve as the basis for a simple chemical test to distinguish between hexanoic acid and hexanamide?

- (a) Cold dilute NaOH (b) Cold dilute NaHCO<sub>3</sub>  
 (c) Cold concd. H<sub>2</sub>SO<sub>4</sub> (d) More than one of these  
 (e) None of these

18.4 Give an acceptable name for:



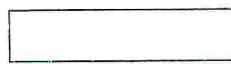
A



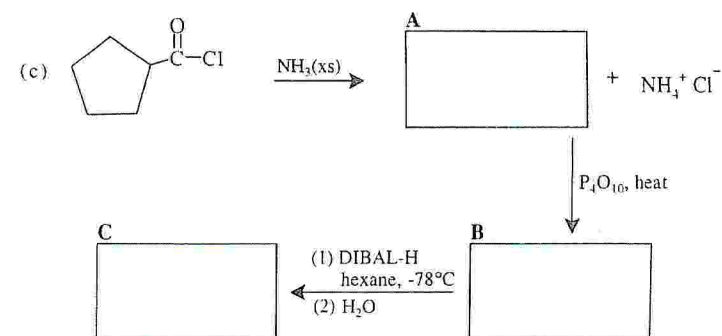
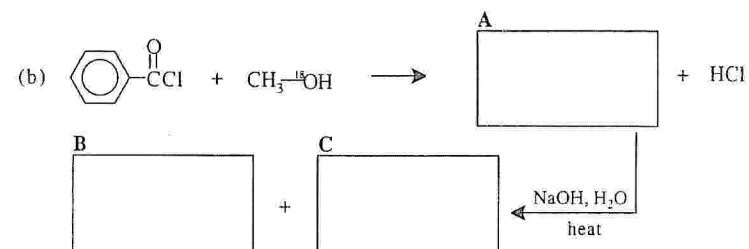
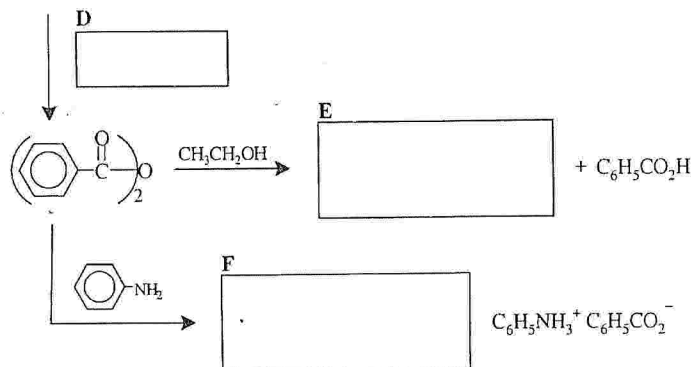
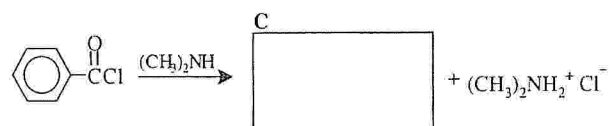
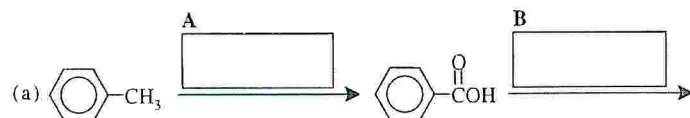
B



C

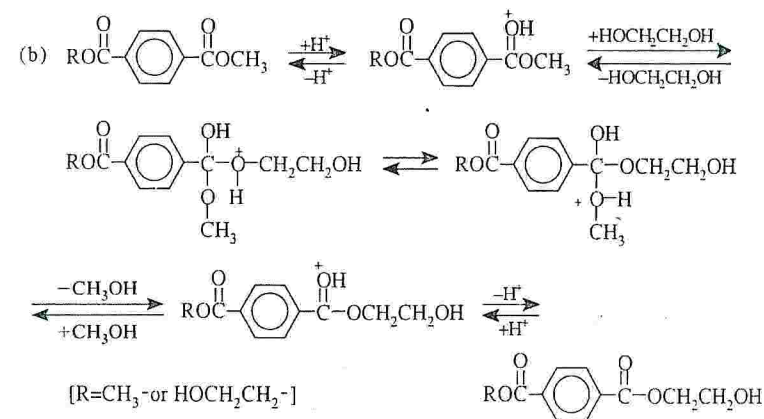
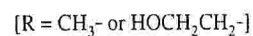
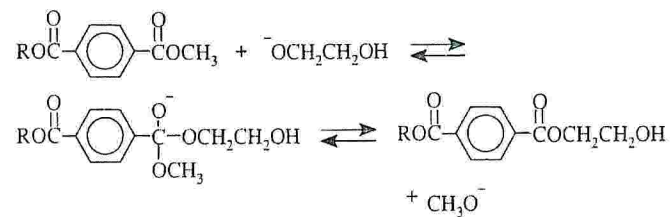
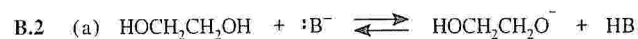
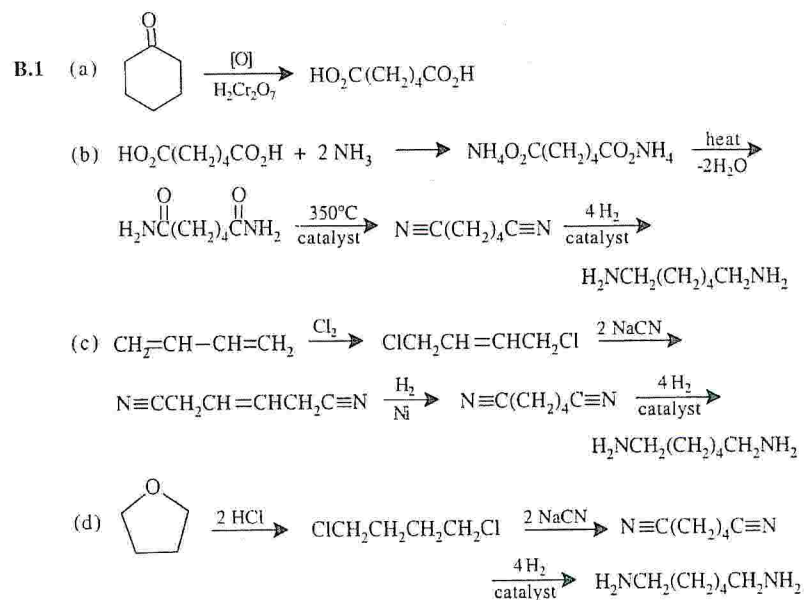


18.5 Complete the following syntheses.

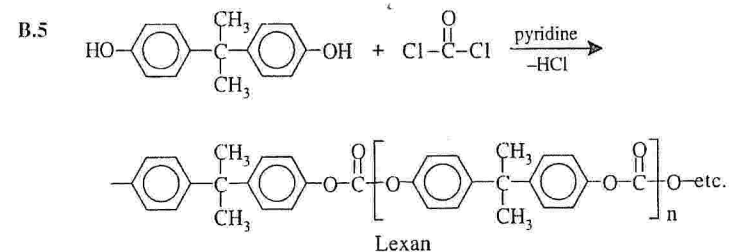
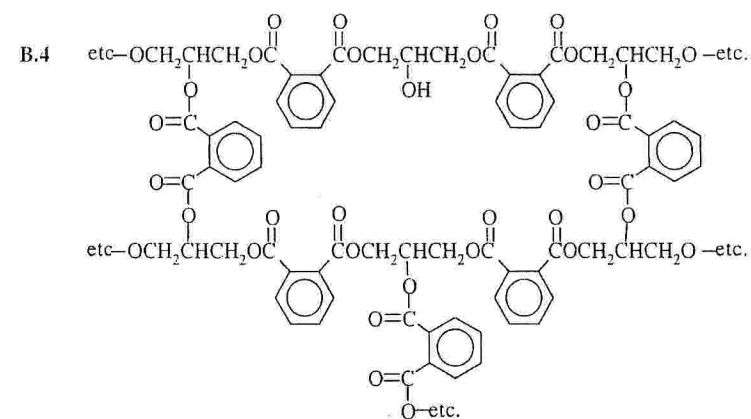




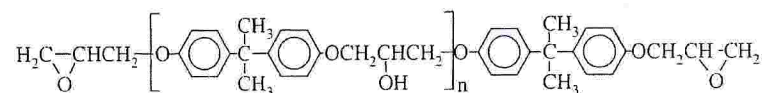
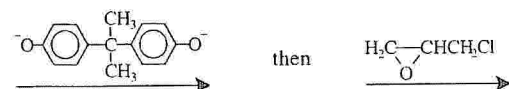
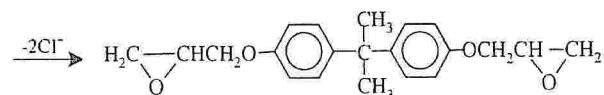
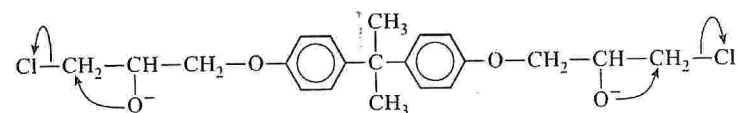
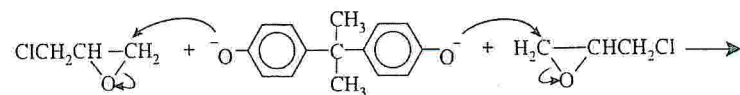
## SOLUTIONS TO PROBLEMS



(b) By high-pressure catalytic hydrogenation

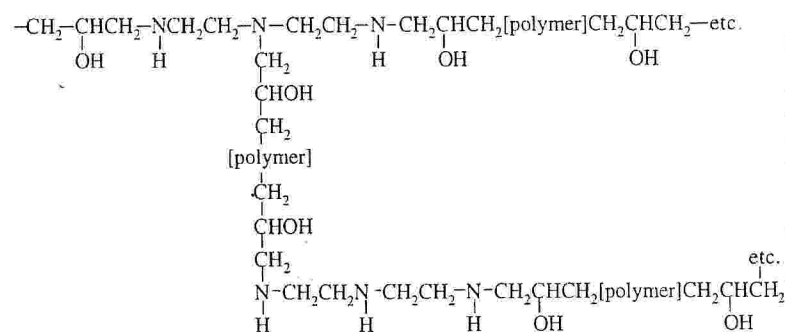
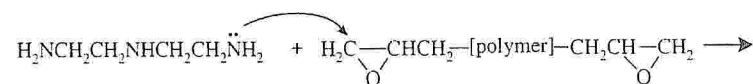


- B.6 (a) The resin is probably formed in the following way. Base converts the bisphenol A to a phenoxide ion that attacks a carbon atom of the epoxide ring of epichlorohydrin:

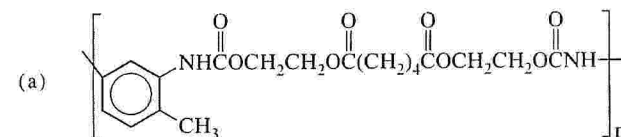


(b) The excess of epichlorohydrin limits the molecular weight and ensures that the resin has epoxy ends.

(c) Adding the hardener brings about cross linking by reacting at the terminal epoxide groups of the resin:

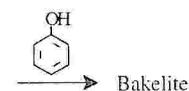
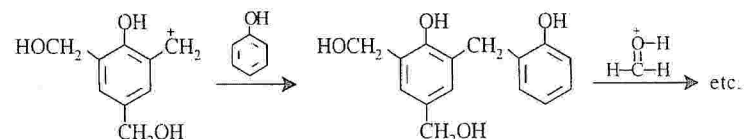
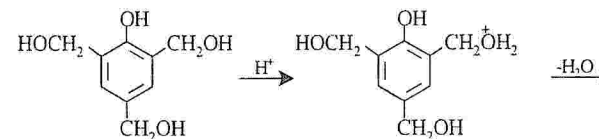
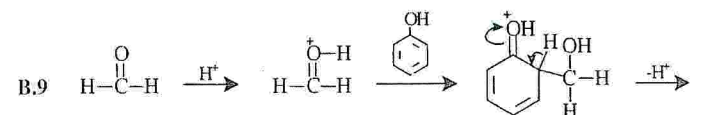


B.7



(b) To ensure that the polyester chain has  $\text{--CH}_2\text{OH}$  end groups.

- B.8 Because the para position is occupied by a methyl group, cross-linking does not occur and the resulting polymer remains thermoplastic (See Section B.4.)

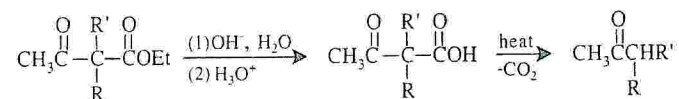
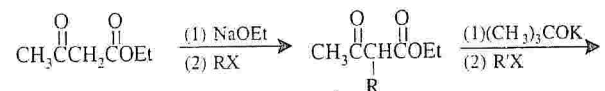


# 19

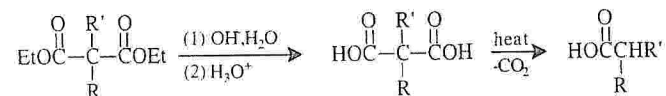
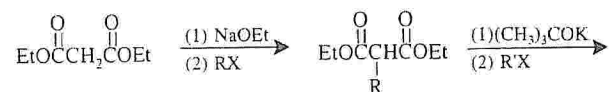
## SYNTHESIS AND REACTIONS OF β-DICARBONYL COMPOUNDS: MORE CHEMISTRY OF ENOLATE ANIONS

### SUMMARY OF ACETOACETIC ESTER AND MALONIC ESTER SYNTHESSES

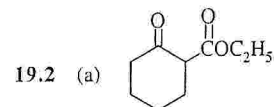
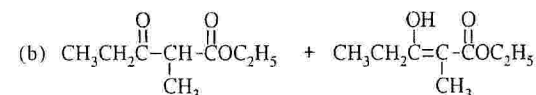
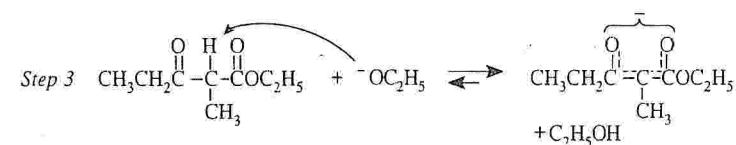
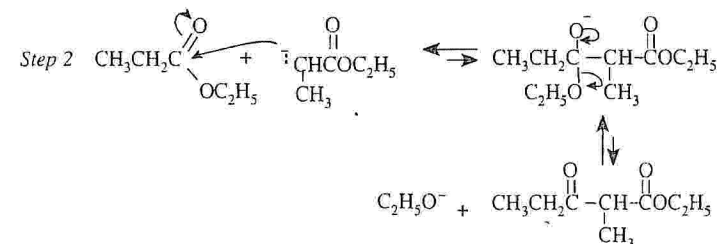
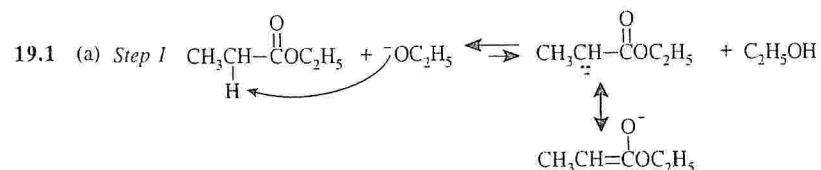
#### A. Acetoacetic Ester Synthesis



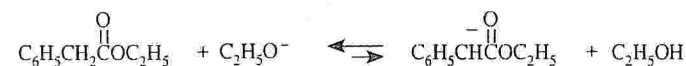
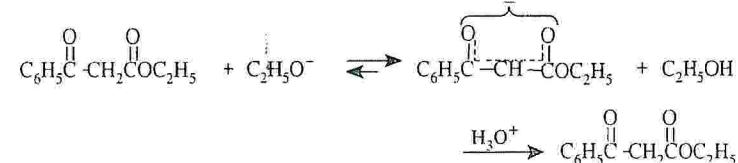
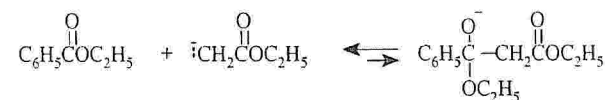
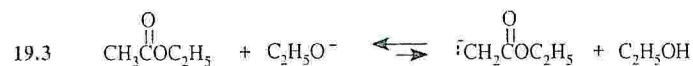
#### B. Malonic Ester Synthesis

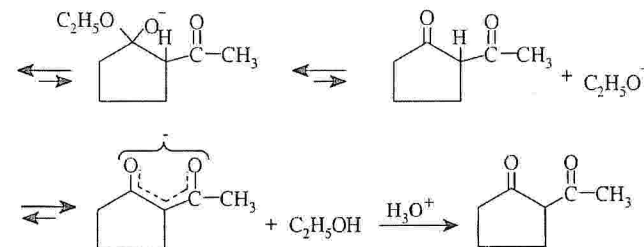
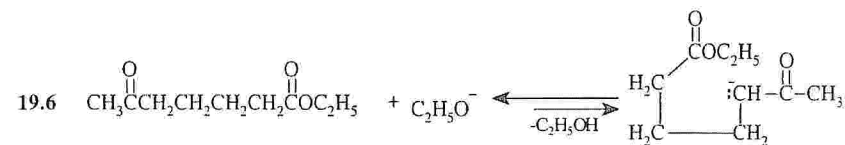
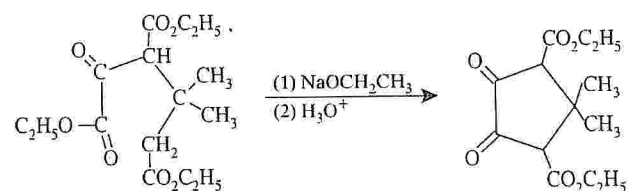
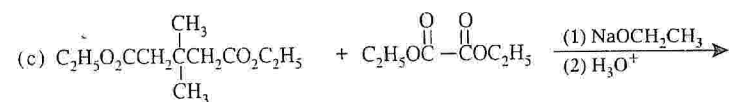
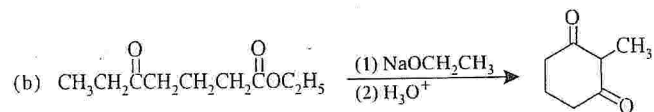
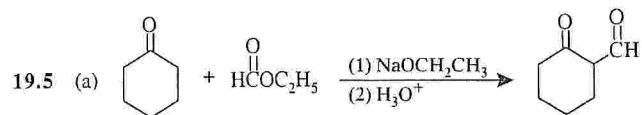
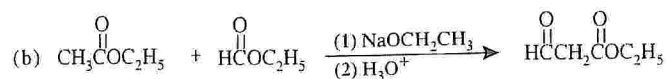
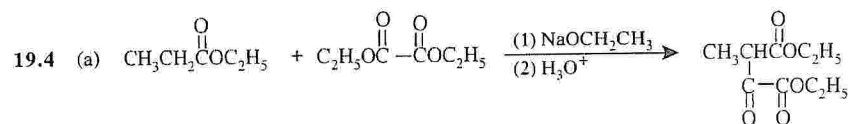
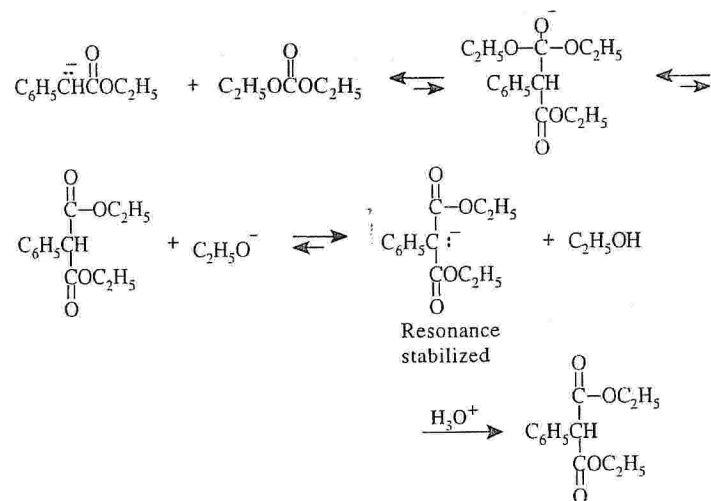


### SOLUTIONS TO PROBLEMS

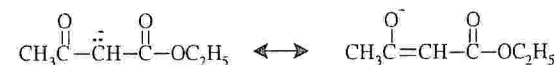


(b) To undergo a Dieckmann condensation, diethyl glutarate would have to form a highly strained four-membered ring.

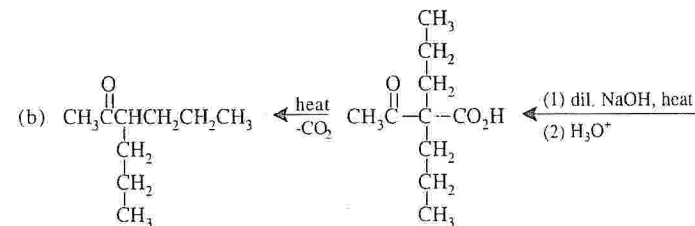
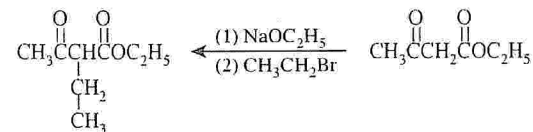
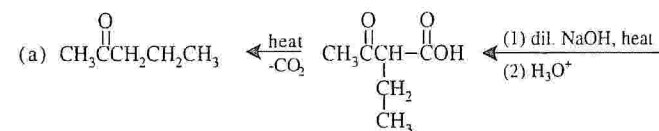




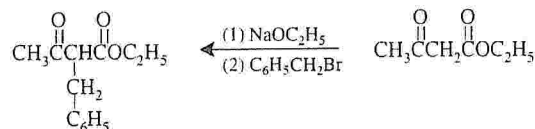
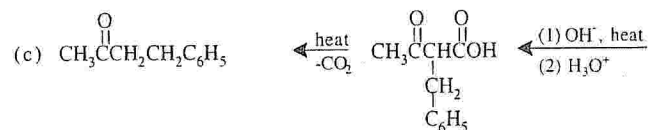
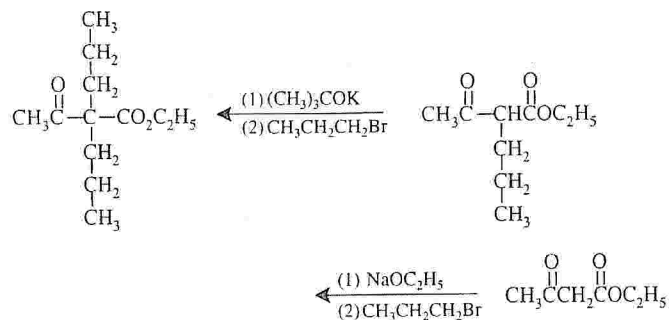
**19.7** The partially negative oxygen atom of sodioacetoacetic ester acts as the nucleophile.



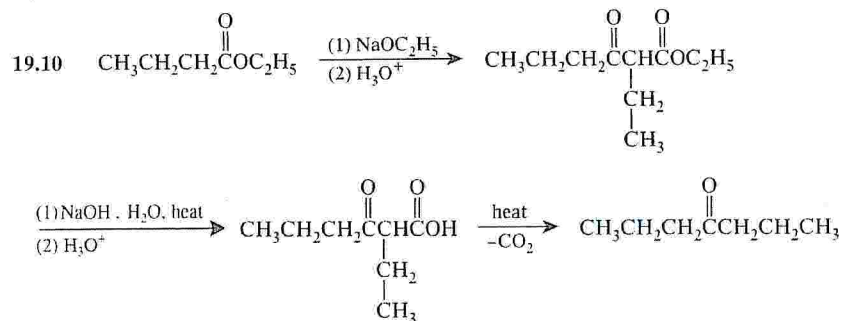
**19.8** Again, working backward,



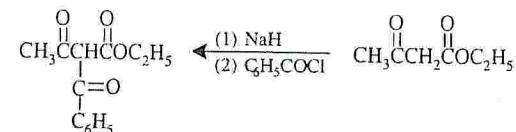
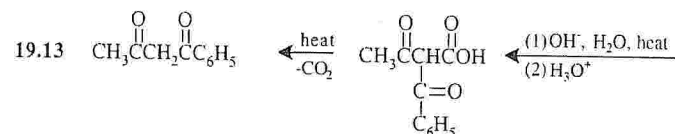
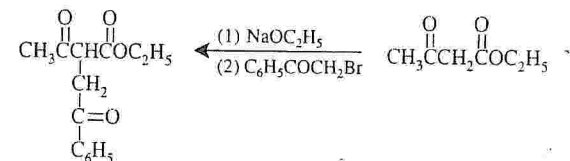
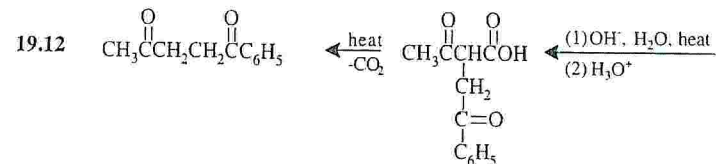




- 19.9 (a) Reactivity is the same as with any  $\text{S}_{\text{N}}2$  reaction. With primary halides substitution is highly favored, with secondary halides elimination competes with substitution, and with tertiary halides elimination is the exclusive course of reaction.
- (b) Acetoacetic ester and 2-methylpropene
- (c) Bromobenzene is unreactive to nucleophilic substitution.



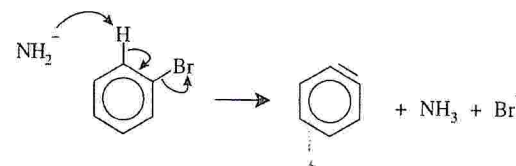
- 19.11 The carboxyl group that is lost more readily is the one that is  $\beta$  to the keto group (cf. Section 18.11 of the text).



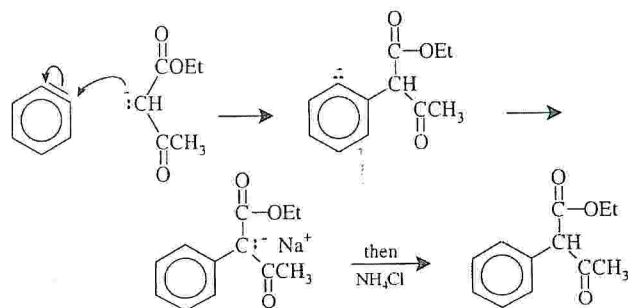
- 19.14 (a) One molar equivalent of  $\text{NaNH}_2$  converts acetoacetic ester to its anion,



and one molar equivalent of  $\text{NaNH}_2$  converts bromobenzene to benzyne (cf. Section 21.11B):

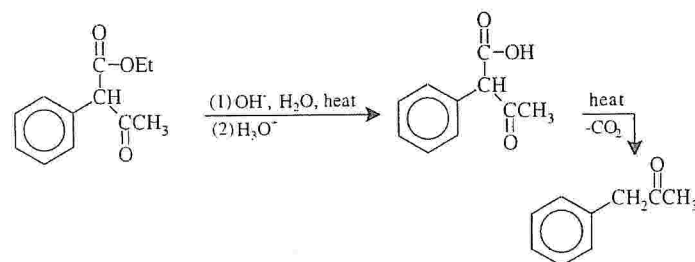


Then the anion of acetoacetic ester adds to the benzyne as it forms in the mixture.

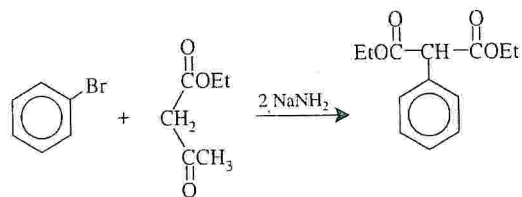


This is the end product of the addition.

(b) 1-phenyl-2-propanone, as follows:

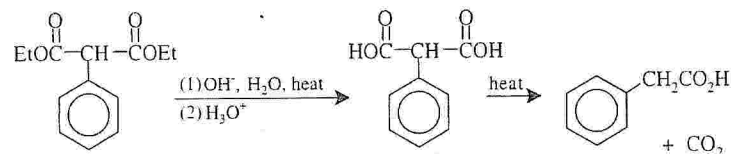


(c) By treating bromobenzene with diethyl malonate and two molar equivalents of  $\text{NaNH}_2$  to form diethyl phenylmalonate.

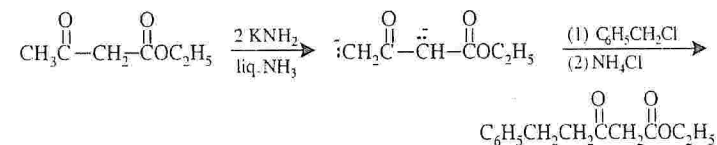


[The mechanism for this reaction is analogous to that given in part (a).]

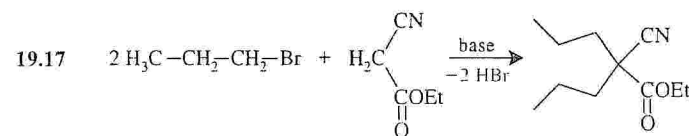
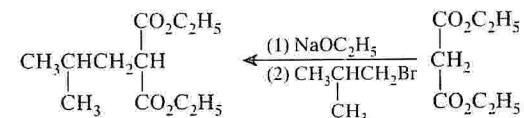
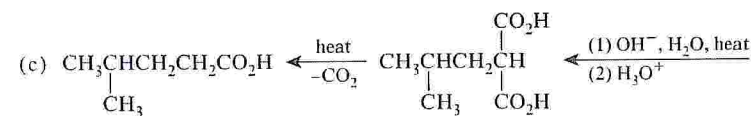
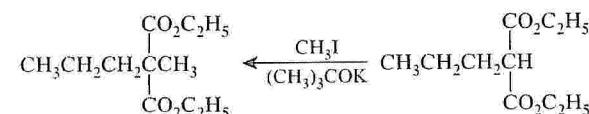
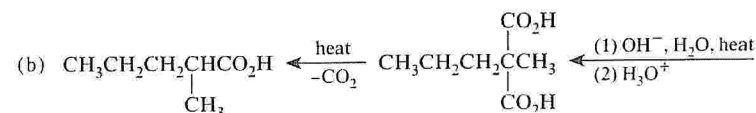
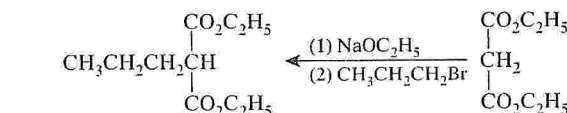
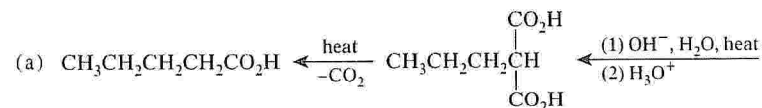
Then hydrolysis and decarboxylation will convert diethyl phenylmalonate to phenylacetic acid.

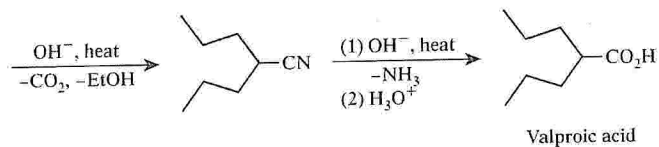


19.15 Here we alkylate the dianion,

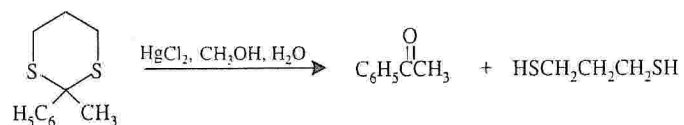
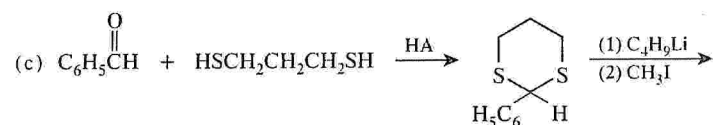
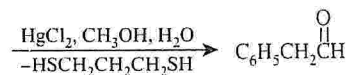
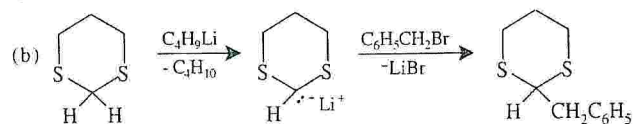


19.16 Working backward,

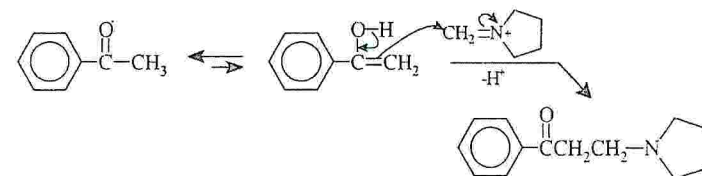
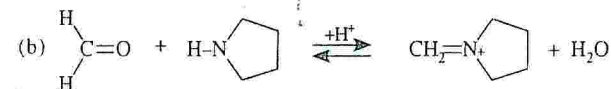
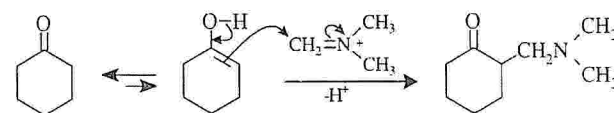
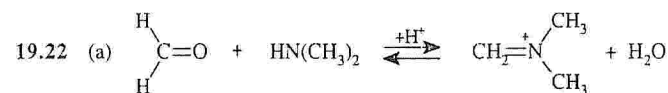
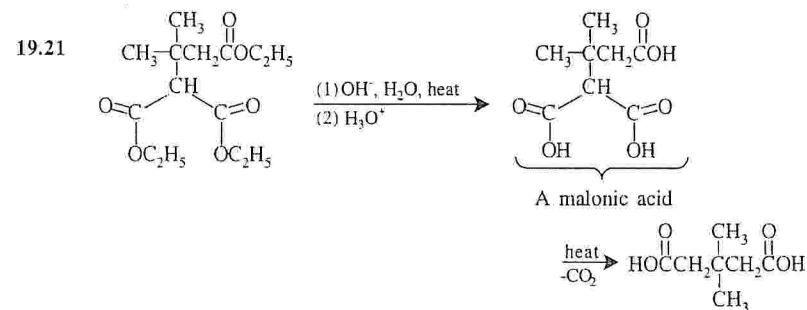
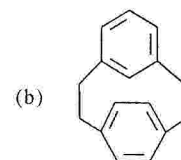
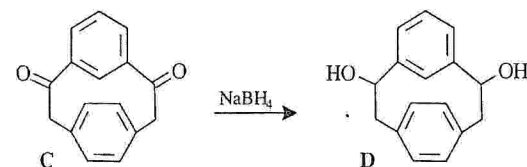
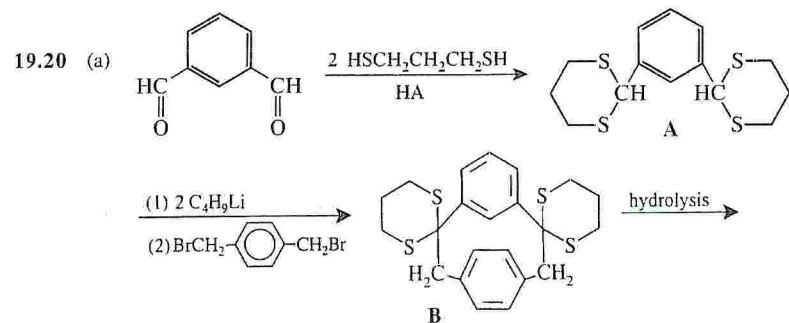
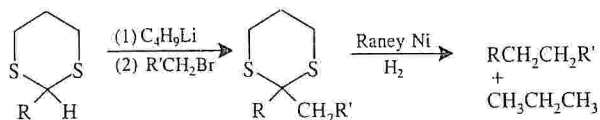


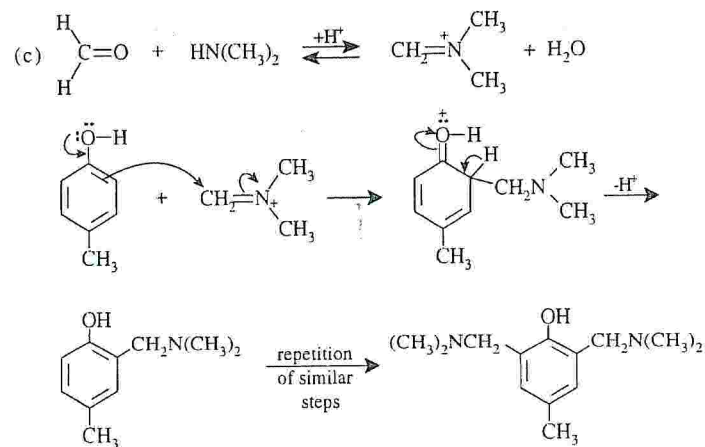


19.18 (a) Formaldehyde,  $\text{H}-\text{C}(=\text{O})-\text{H}$

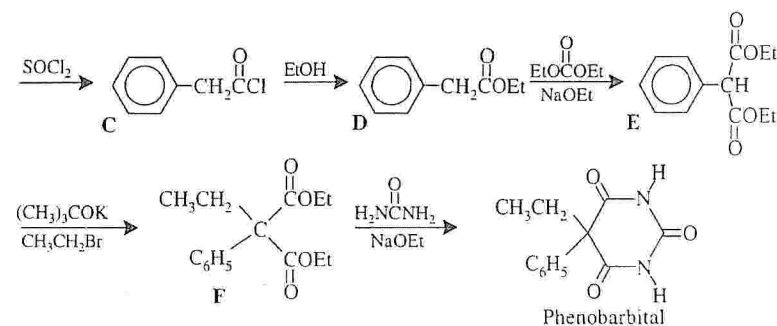
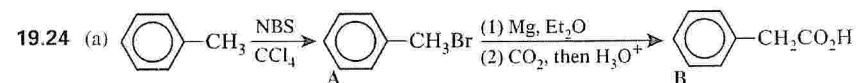
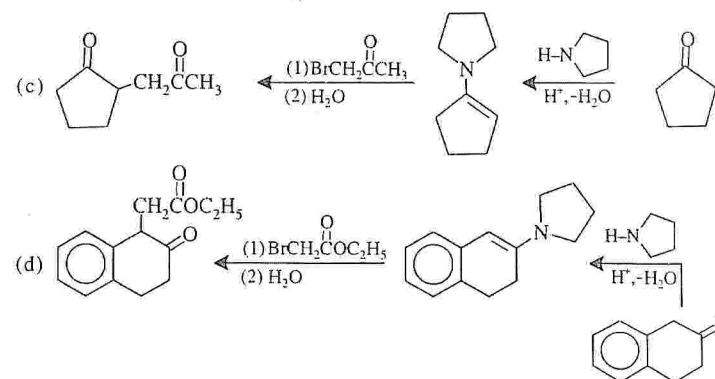
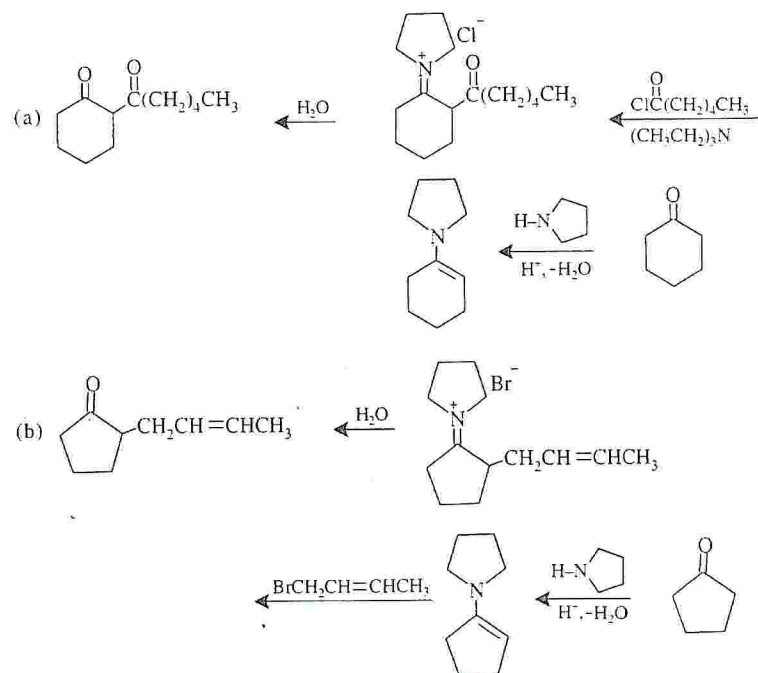


19.19 By treating the thioketal with Raney nickel.

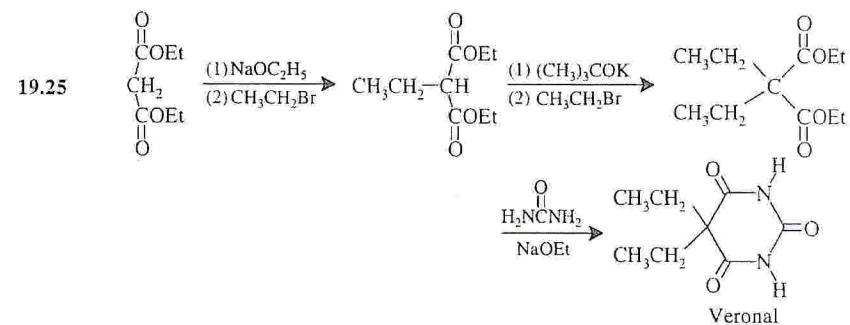




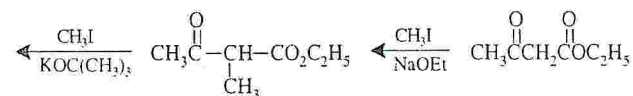
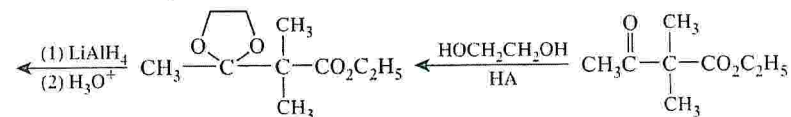
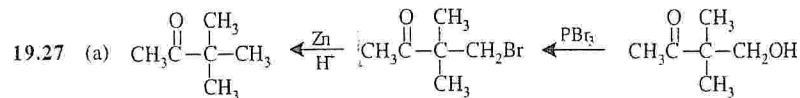
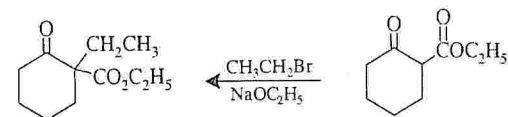
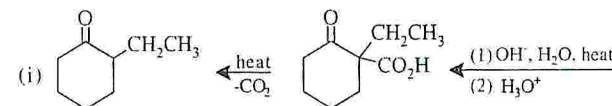
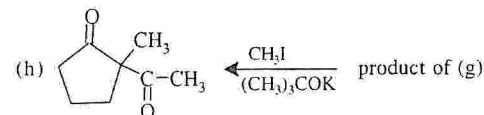
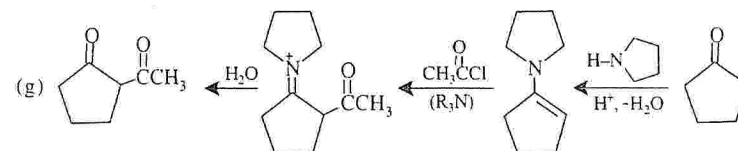
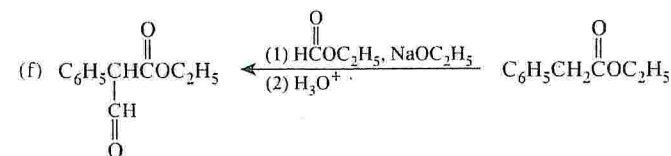
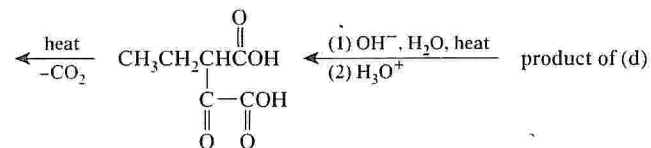
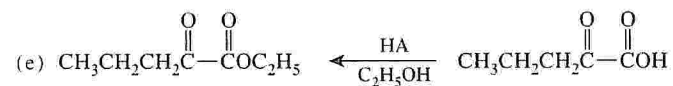
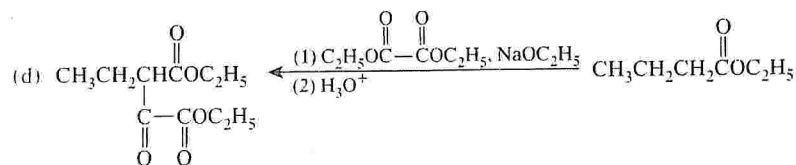
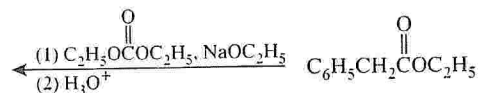
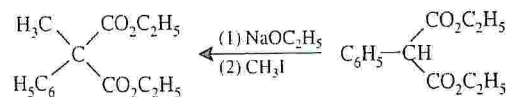
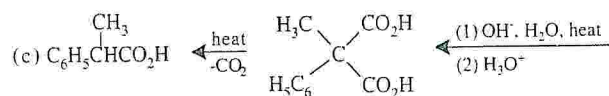
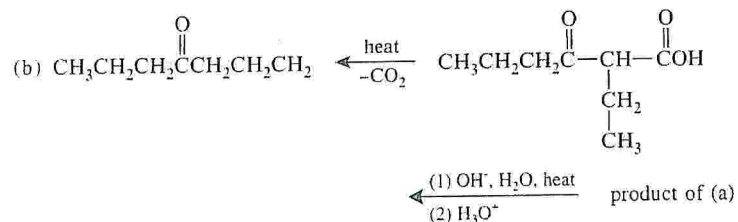
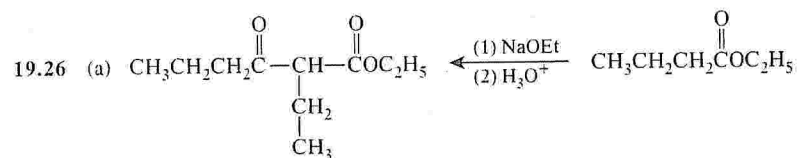
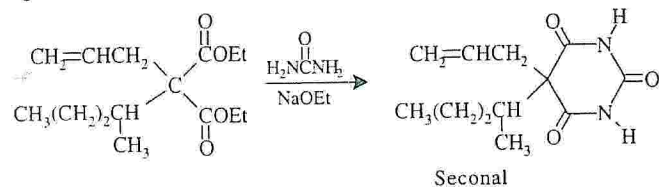
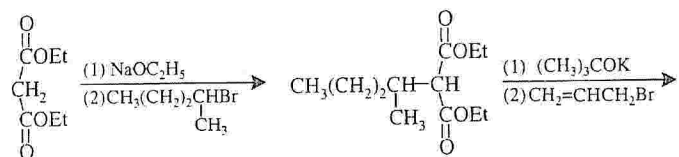
19.23 These syntheses are easier to see if we work backward.

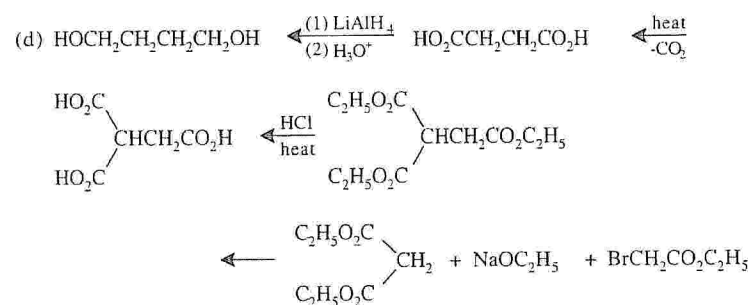
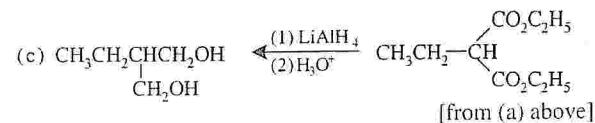
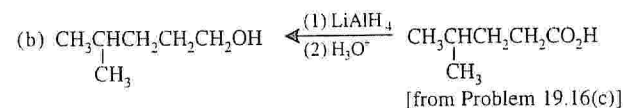
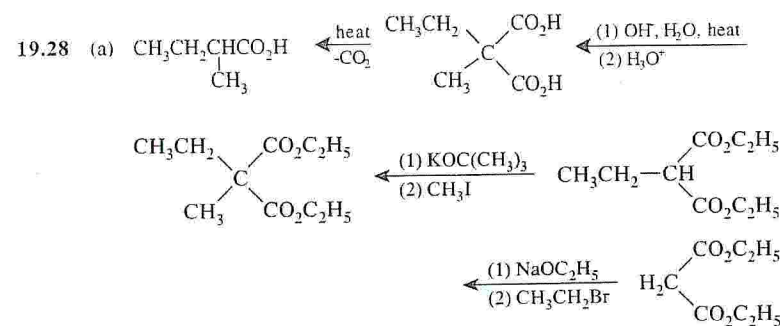
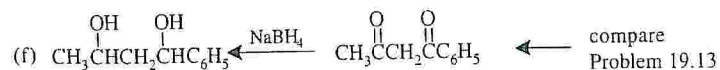
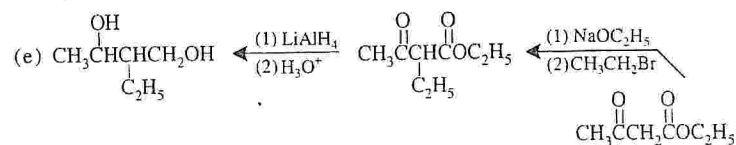
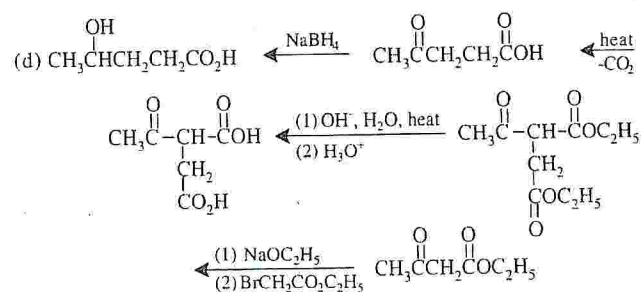
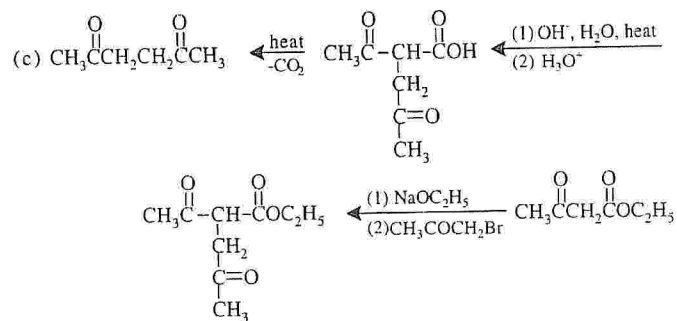
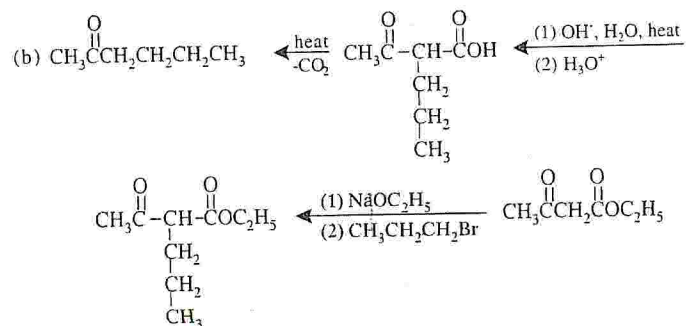


(b) See Section 19.3.

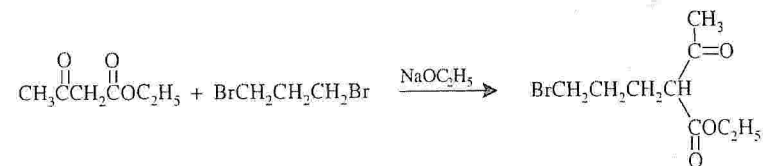


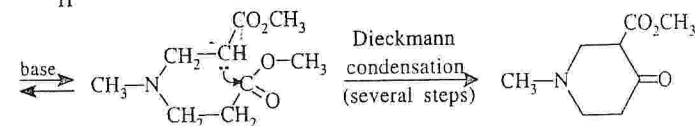
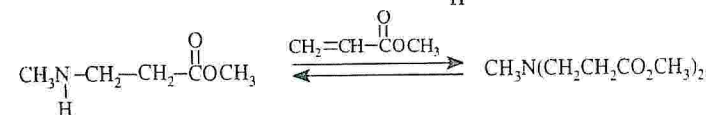
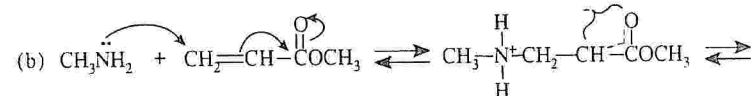
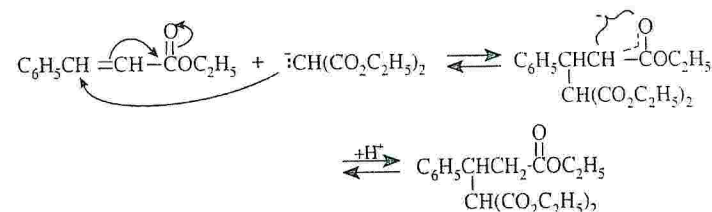
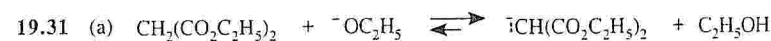
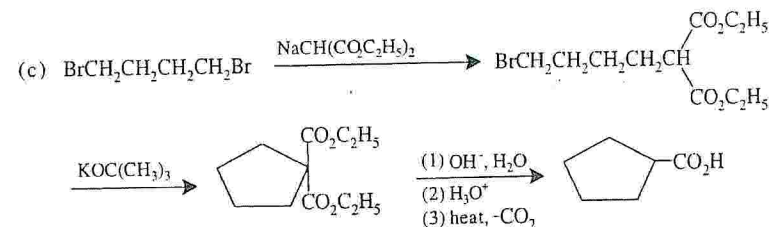
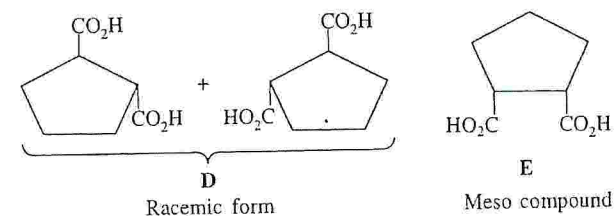
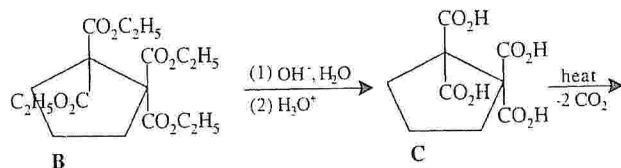
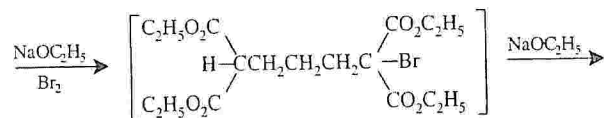
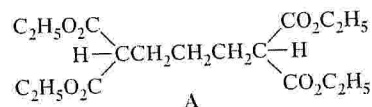
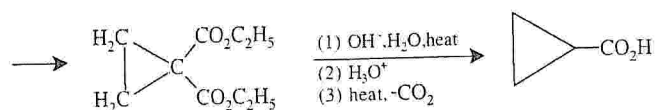
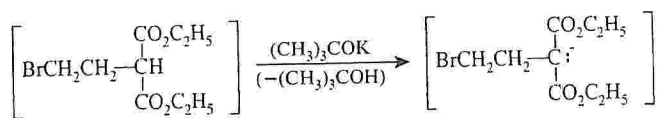
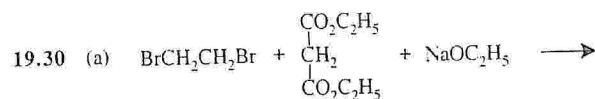
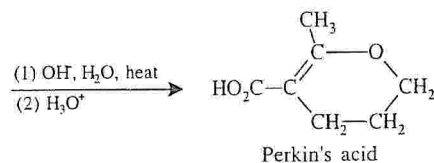
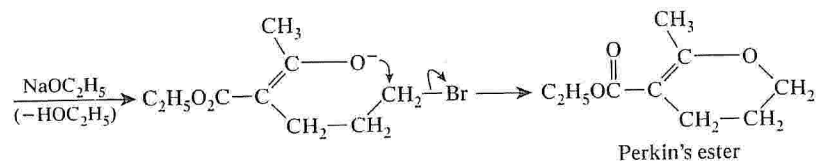


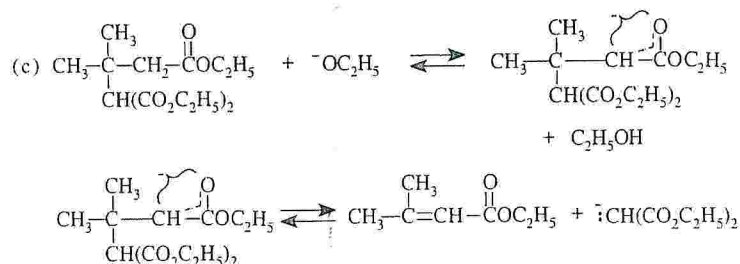




19.29 The following reaction took place:

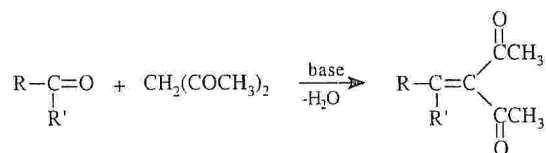




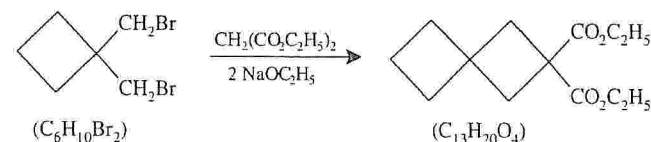
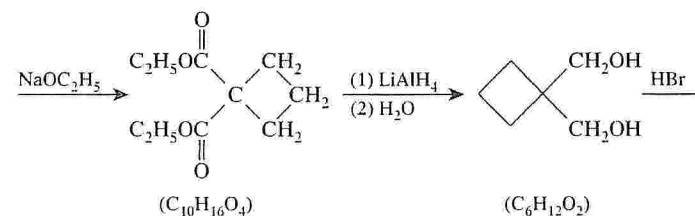
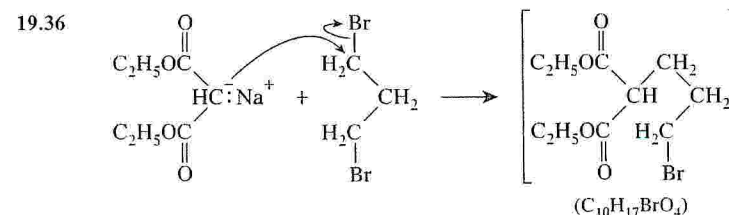
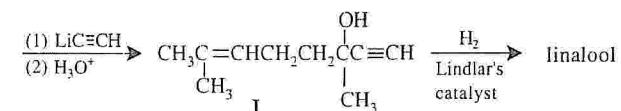
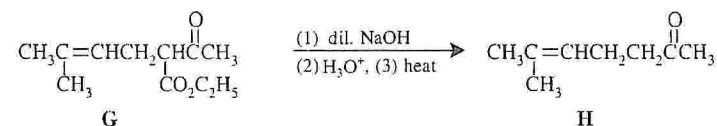
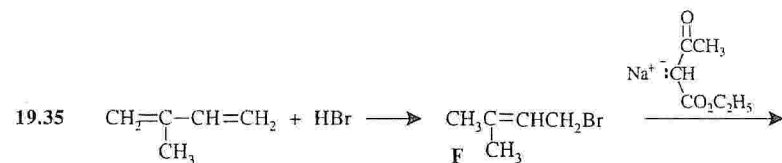
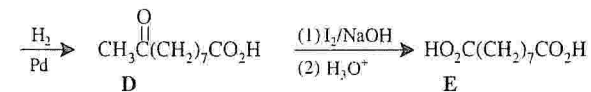
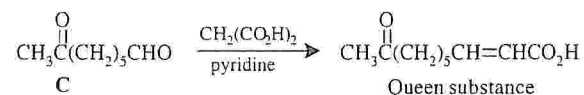
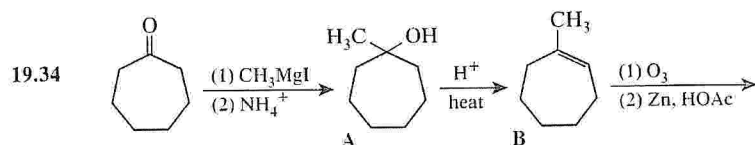
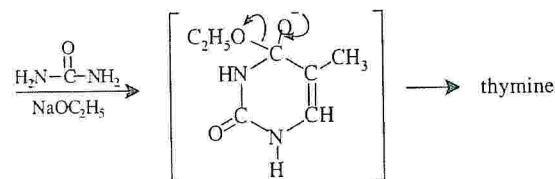
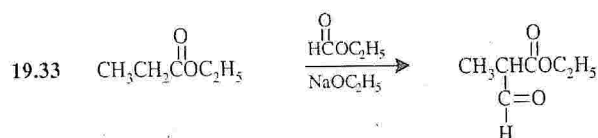
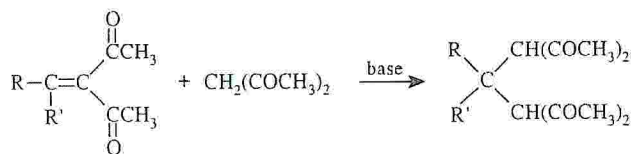


The Michael reaction is reversible, and the reaction just given is an example of a reverse Michael reaction.

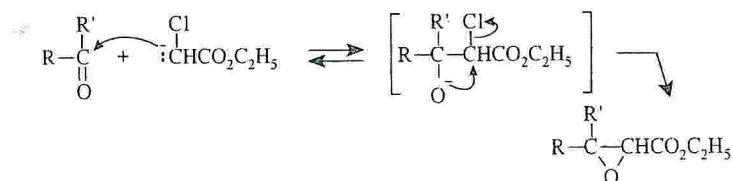
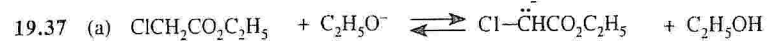
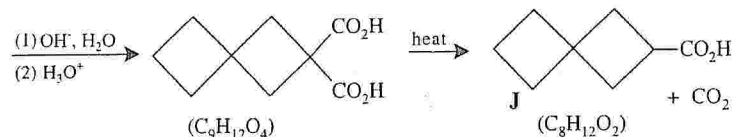
**19.32** Two reactions take place. The first is a normal Knoevenagel condensation,



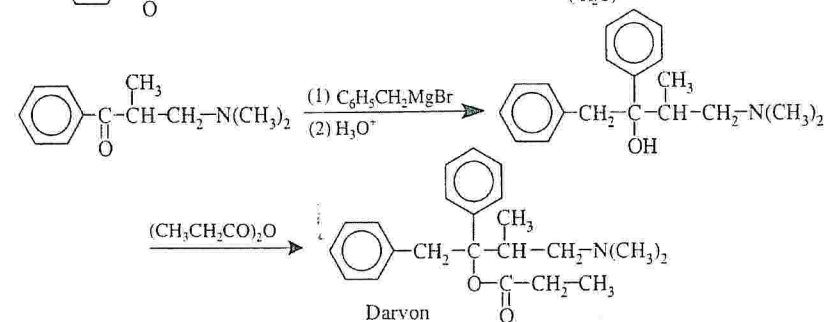
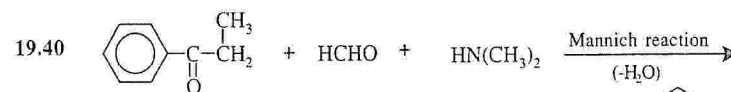
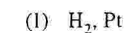
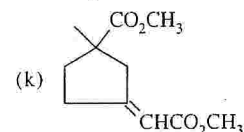
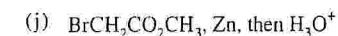
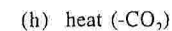
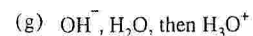
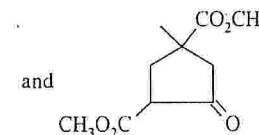
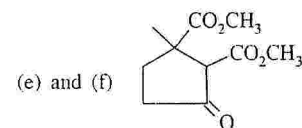
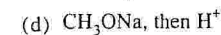
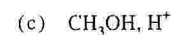
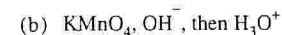
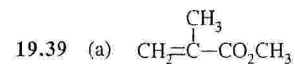
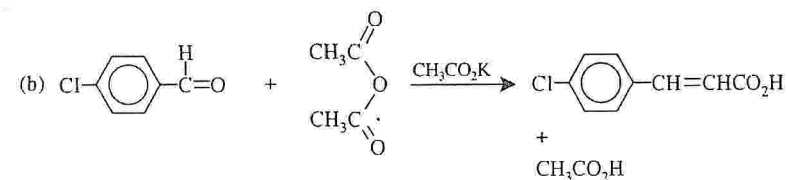
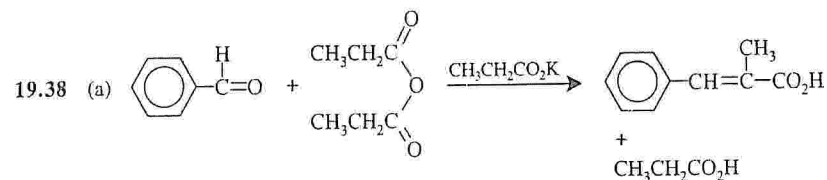
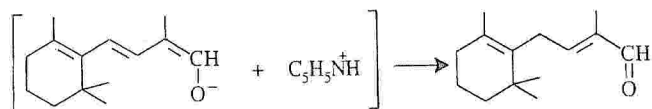
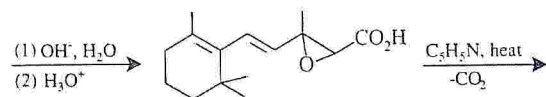
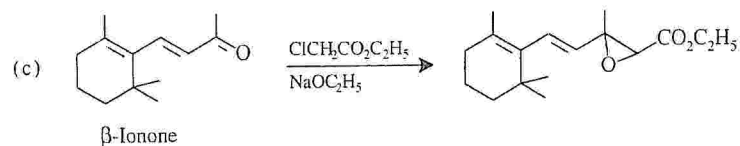
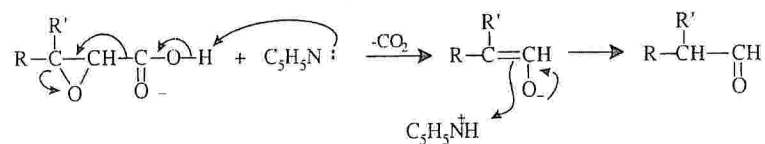
Then the  $\alpha$ ,  $\beta$ -unsaturated diketone reacts with a second mole of the active methylene compound in a Michael addition.





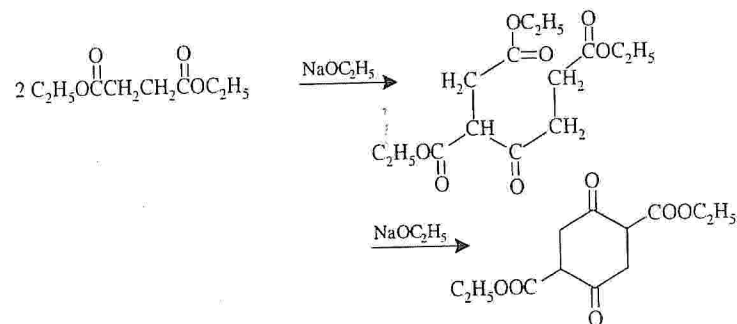


(b) Decarboxylation of the epoxy acid gives an enol anion which, on protonation, gives an aldehyde.



19.41 In a polar solvent, such as water, the keto form is stabilized by solvation. When the interaction with the solvent becomes minimal, the enol form achieves stability by internal hydrogen bonding.

- 19.42** Intramolecular cyclization (which would give a product of formula  $C_6H_8O_3$ ) is not favored because of ring strain. The formula of the product actually obtained suggests a 1:1 intermolecular reaction:

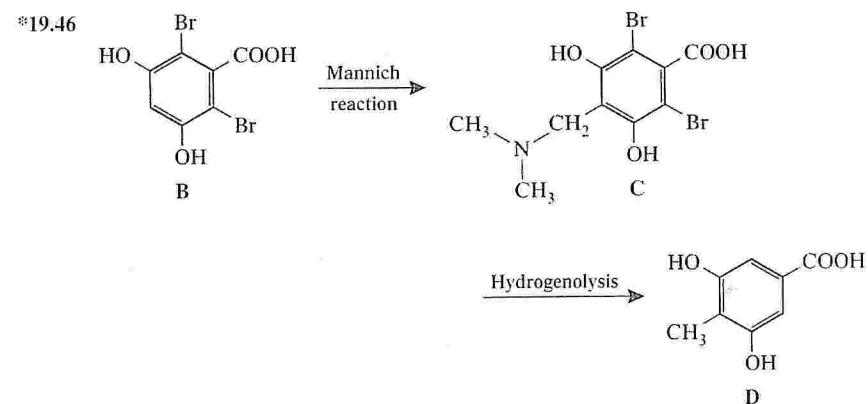
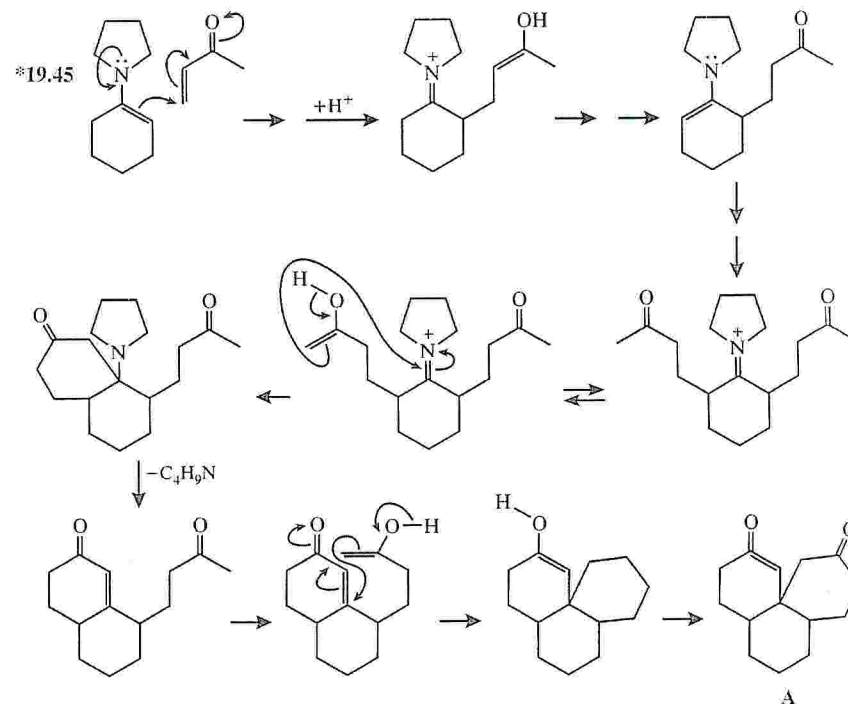
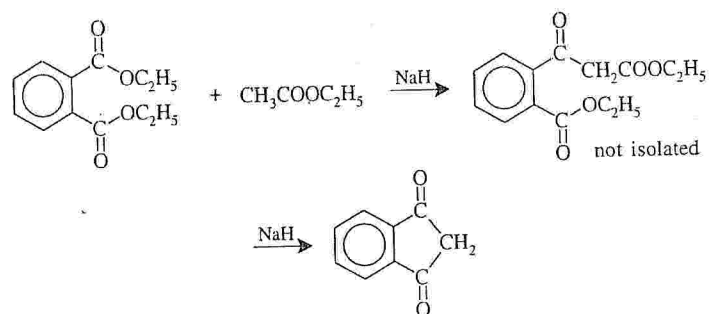


- 19.43** A gamma hydrogen is abstracted by base (as is an alpha hydrogen in the usual Claisen) to give a resonance-stabilized species:



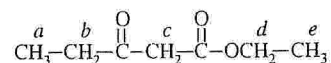
Ethyl crotonate differs from ethyl acetate by  $-\text{CH}=\text{CH}-$ , a vinyl group. The transmission of the stabilizing effect of the  $-\text{COOC}_2\text{H}_5$  group is an example of the principle of vinylogy.

- 19.44** The synthesis actually involves two sequential Claisen condensations, with ethyl acetate serving as the source of the carbanionic species.



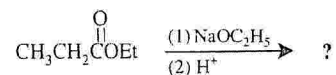
## QUIZ

- 19.1 Which hydrogen atoms in the following ester are most acidic?



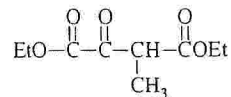
- (a)
- a*
- (b)
- b*
- (c)
- c*
- (d)
- d*
- (e)
- e*

- 19.2 What would be the product of the following reaction?



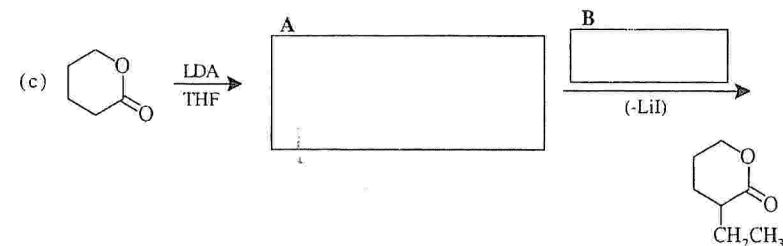
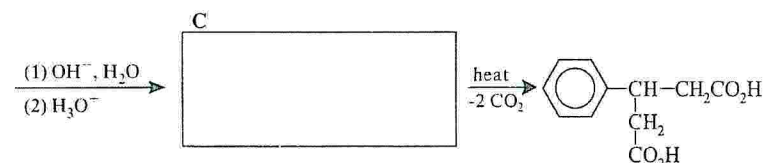
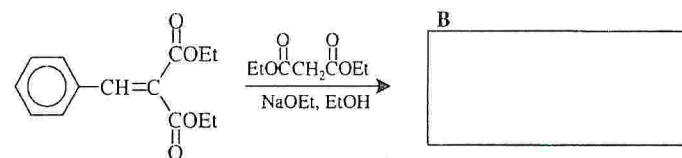
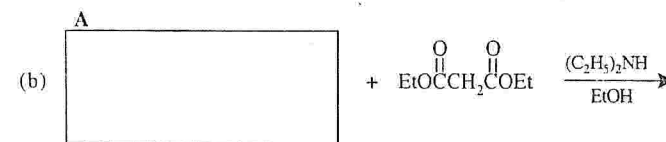
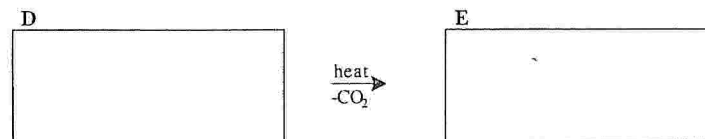
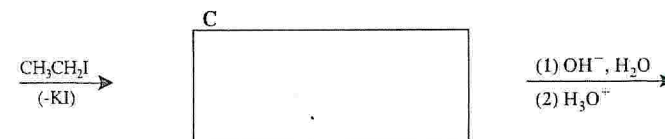
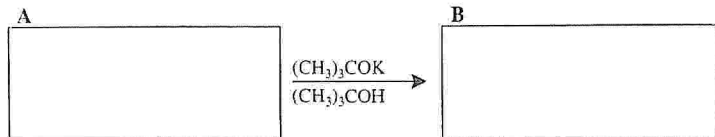
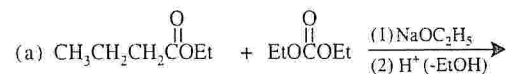
- (a)  $\text{CH}_3\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{CH}_2\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{OEt}$       (b)  $\text{CH}_3\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{CH}_3$   
 (c)  $\text{CH}_3\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{OEt}$       (d)  $\text{CH}_3\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{CH}_2\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{OEt}$   
 (e)  $\text{CH}_3\text{CH}_2\overset{\text{O}}{\overset{\parallel}{\text{C}}}\underset{\text{CH}_3}{\text{CH}}\overset{\text{O}}{\overset{\parallel}{\text{C}}}\text{OEt}$

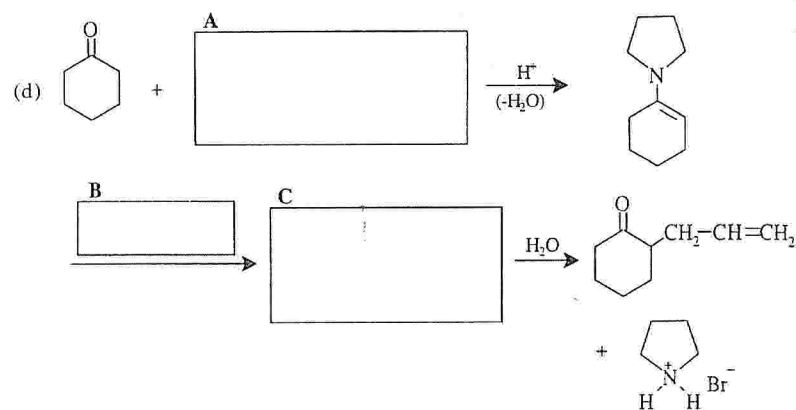
- 19.3 What starting materials could be used in a crossed Claisen condensation to prepare the following compound?



- (a)  $\text{CH}_3\text{CO}_2\text{Et}$  and  $\text{EtO}-\overset{\text{O}}{\overset{\parallel}{\text{C}}}-\overset{\text{O}}{\overset{\parallel}{\text{C}}}-\text{CH}_2\text{CH}_3$       (d)  $\text{EtO}_2\text{CCH}(\text{CH}_3)\text{CO}_2\text{Et}$  and  $\text{HCO}_2\text{Et}$   
 (b)  $\text{CH}_3\text{CH}_2\text{CO}_2\text{Et}$  and  $\text{EtO}_2\text{C}-\text{CO}_2\text{Et}$       (e) More than one of the above  
 (c)  $\text{CH}_3\text{CH}_2\text{CO}_2\text{Et}$  and  $\text{HCO}_2\text{Et}$

- 19.4 Supply the missing reagents, intermediates, and products.



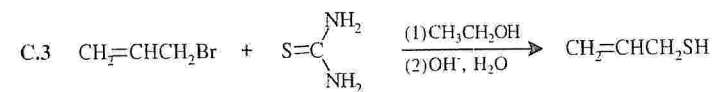
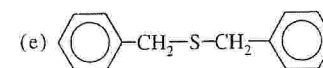
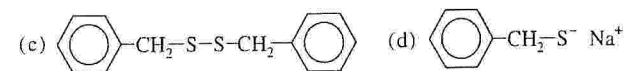
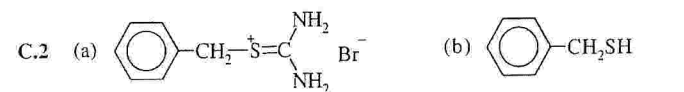
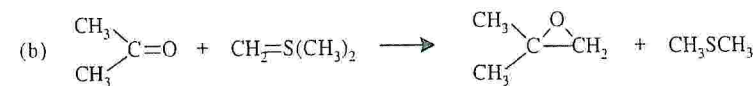
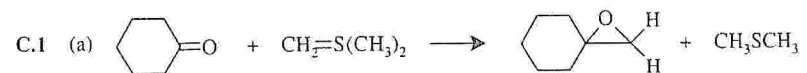


## C

## SPECIAL TOPIC

Thiols, Sulfur Ylides, and Disulfides

## SOLUTIONS TO PROBLEMS



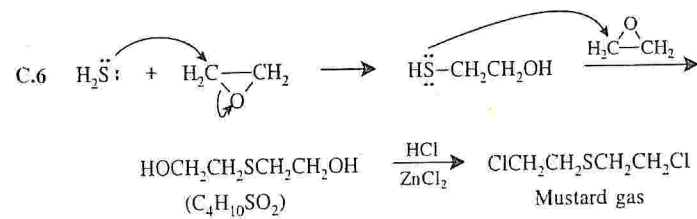
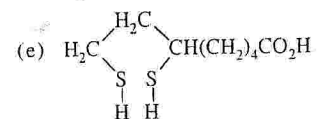


C.5 (a)  $\text{ClCH}_2\text{CH}_2\text{C}(=\text{O})(\text{CH}_2)_4\text{CO}_2\text{C}_2\text{H}_5$  (This step is the Friedel-Crafts alkylation of an alkene)

(b)  $\text{SOCl}_2$

(c) 2  $\text{C}_6\text{H}_5\text{CH}_2\text{SH}$  and  $\text{KOH}$

(d)  $\text{H}_3\text{O}^+$



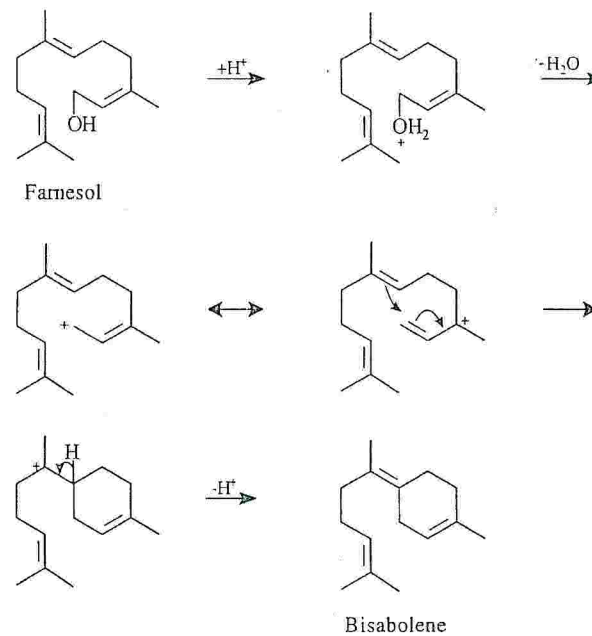
# D

## SPECIAL TOPIC

### Thiol Esters and Lipid Biosynthesis

#### SOLUTIONS TO PROBLEM

D.1

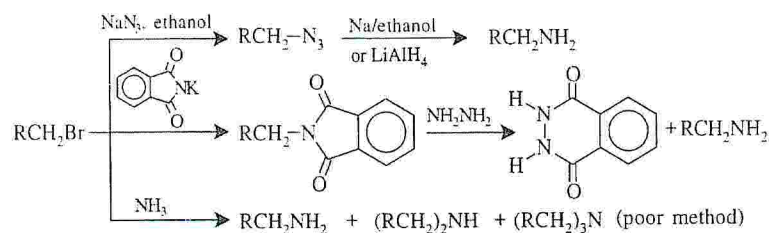


# 20 AMINES

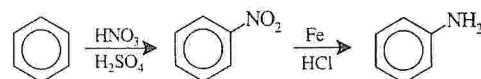
## PREPARATION AND REACTIONS OF AMINES

### A. Preparation

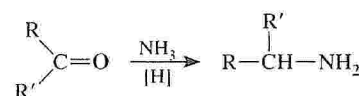
#### 1. Preparation via nucleophilic substitution reactions.



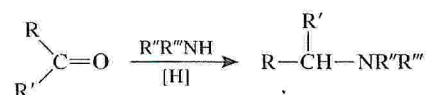
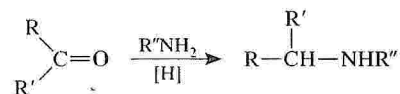
#### 2. Preparation through reduction of nitro compounds.



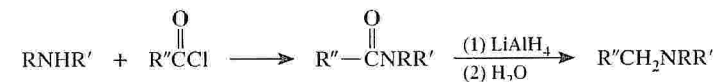
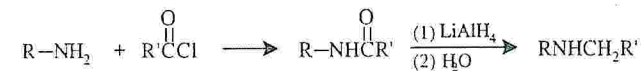
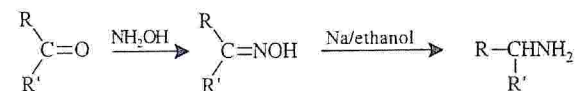
#### 3. Preparation via reductive amination.



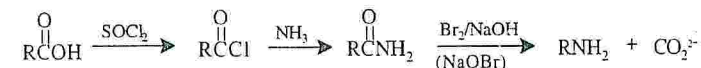
Aldehyde or ketone



#### 4. Preparation of amines through reduction of amides, oximes, and nitriles.



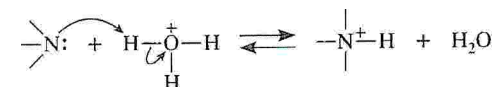
#### 5. Preparation through the Hofmann rearrangement of amides.



### B. Reaction of Amines

#### 1. As a base or a nucleophile

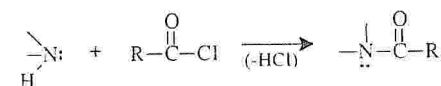
As a base



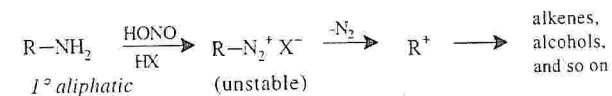
As a nucleophile in alkylation

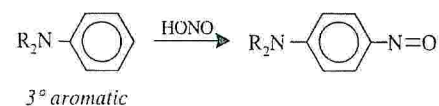
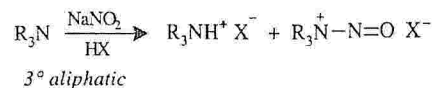
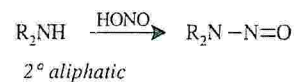
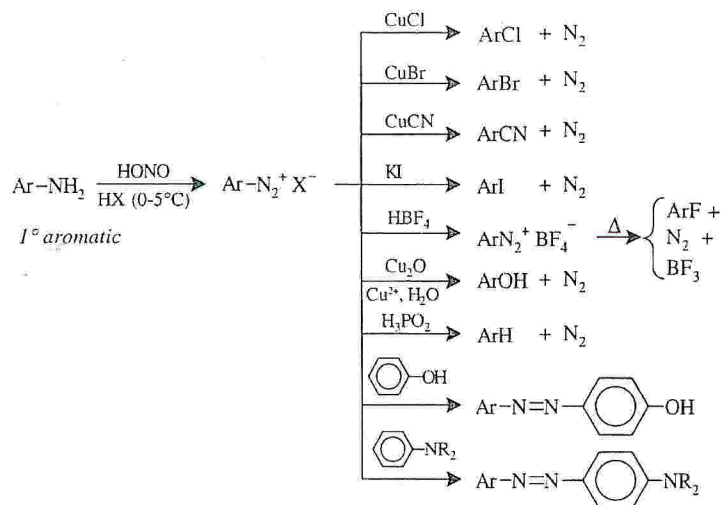


As a nucleophile in acylation

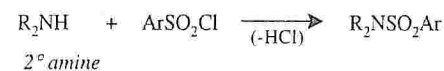


#### 2. With nitrous acid

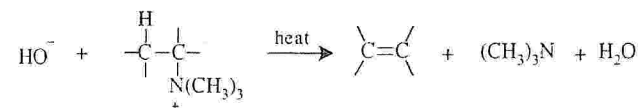




## 3. With sulfonyl chlorides

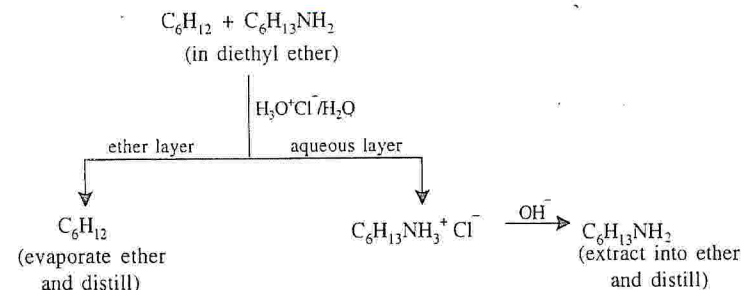


## 4. The Hofmann elimination

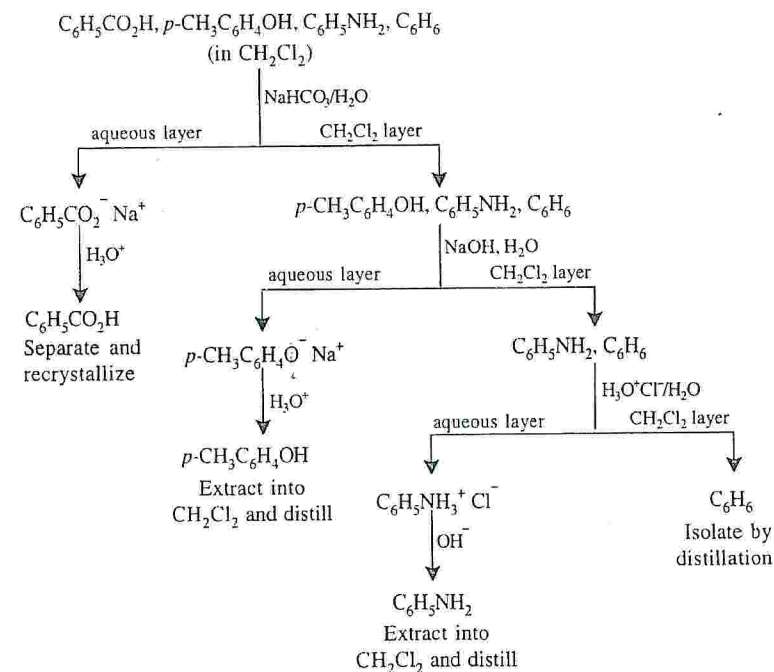


## SOLUTIONS TO PROBLEMS

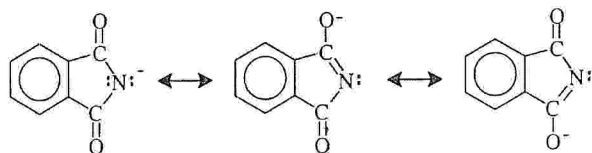
- 20.1 Dissolve both compounds in diethyl ether and extract with aqueous HCl. This procedure gives an ether layer that contains cyclohexane and an aqueous layer that contains hexylaminium chloride. Cyclohexane may then be recovered from the ether layer by distillation. Hexylamine may be recovered from the aqueous layer by adding aqueous NaOH (to convert hexylaminium chloride to the hexylamine) and then by ether extraction and distillation.



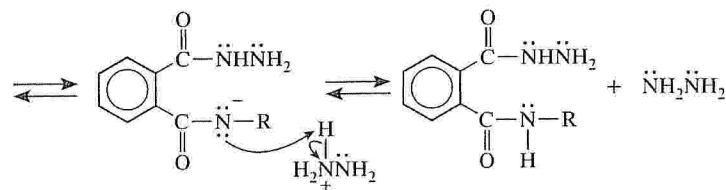
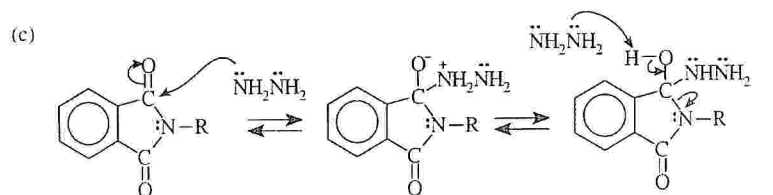
- 20.2 We begin by dissolving the mixture in a water-immiscible organic solvent such as  $\text{CH}_2\text{Cl}_2$  or diethyl ether. Then, extractions with aqueous acids and bases allow us to separate the components. [We separate 4-methylphenol (*p*-cresol) from benzoic acid by taking advantage of benzoic acid's solubility in the more weakly basic aqueous  $\text{NaHCO}_3$ , whereas *p*-cresol requires the more strongly basic, aqueous NaOH.]



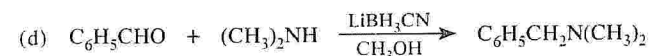
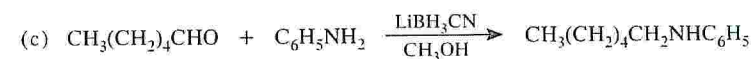
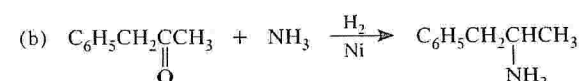
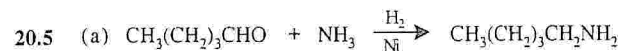
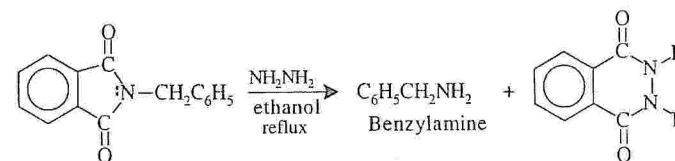
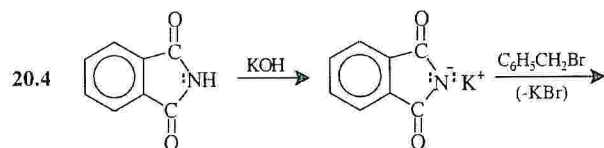
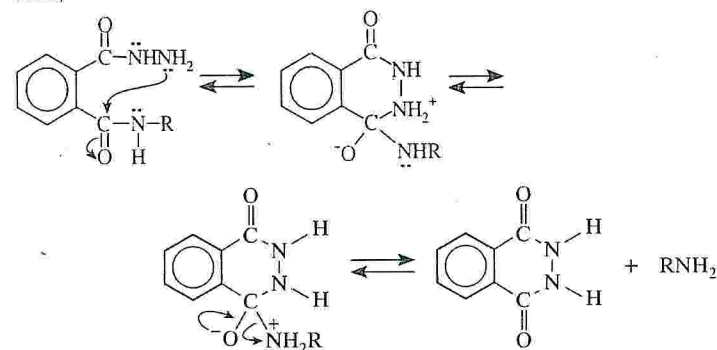
- 20.3 (a) Neglecting Kekulé forms of the ring, we can write the following resonance structures for the phthalimide anion.



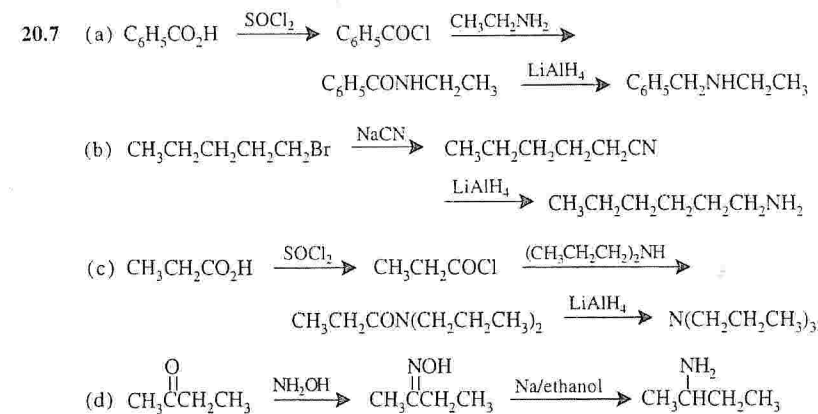
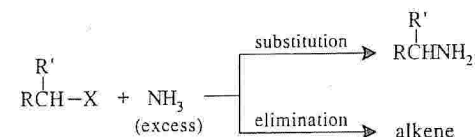
- (b) Phthalimide is more acidic than benzamide because its anion is stabilized by resonance to a greater extent than the anion of benzamide. (Benzamide has only one carbonyl group attached to the nitrogen atom, and thus fewer resonance contributors are possible.)



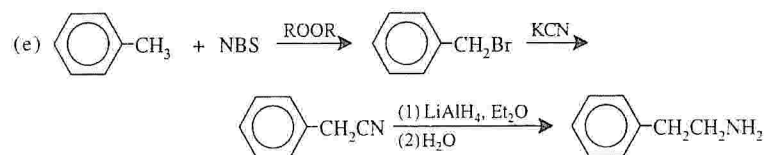
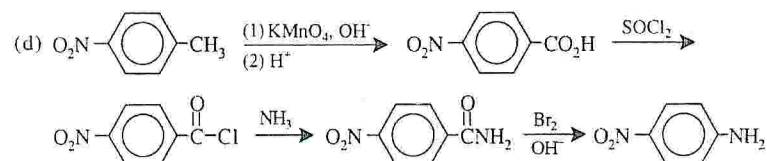
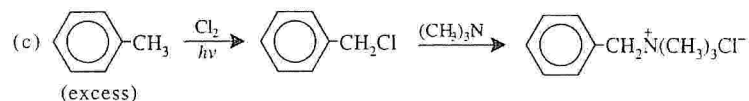
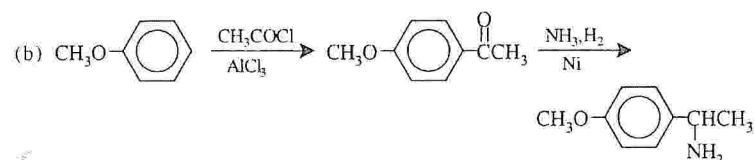
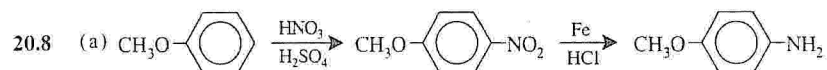
Then,



- 20.6 The reaction of a secondary halide with ammonia would inevitably be accompanied by considerable elimination, thus decreasing the yield.



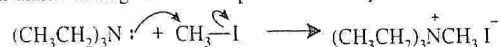




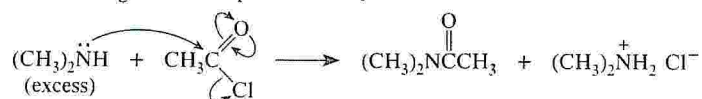
20.9 An amine acting as a base.



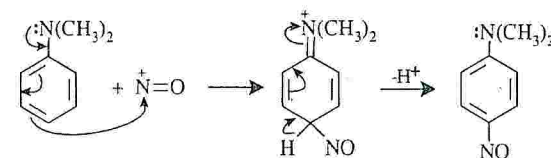
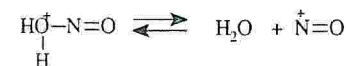
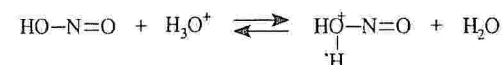
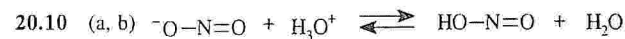
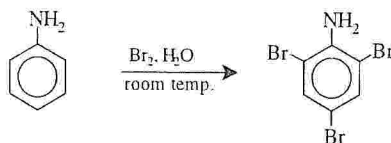
An amine acting as a nucleophile in an alkylation reaction.



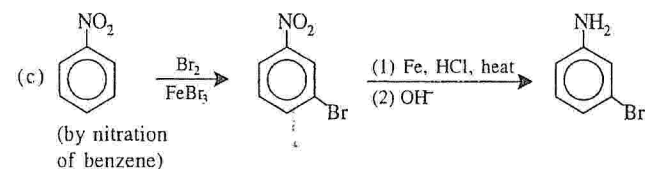
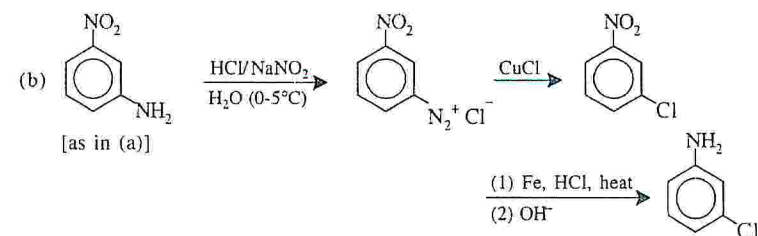
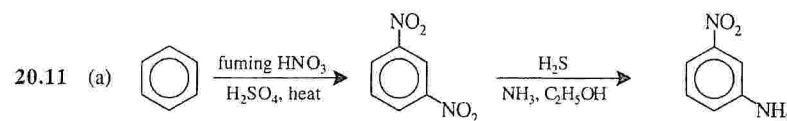
An amine acting as a nucleophile in an acylation reaction.



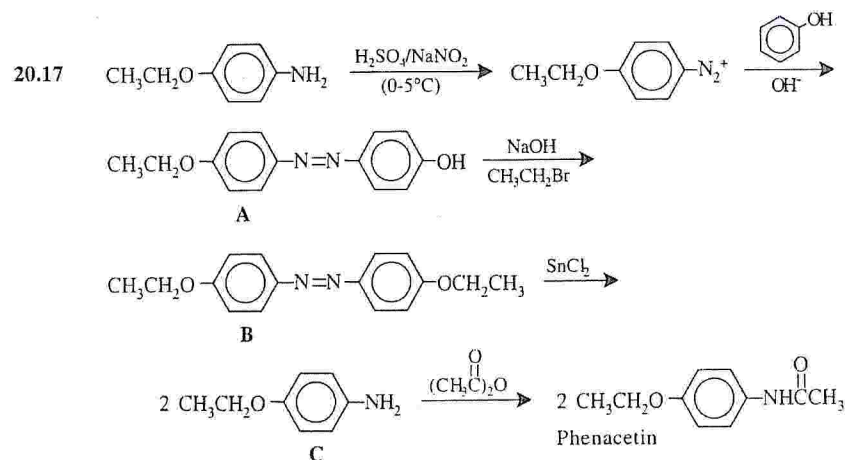
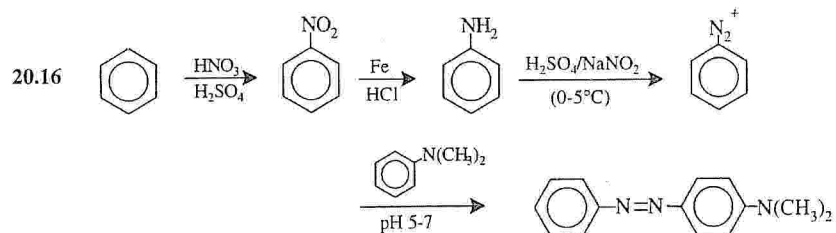
An amino group acting as an activating group and as an ortho-para director in electrophilic aromatic substitution.



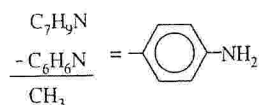
(c) The  $\text{NO}^+$  ion is a weak electrophile. For it to react with an aromatic ring, the ring must have a powerful activating group such as  $-\text{OH}$  or  $-\text{NR}_2$ .





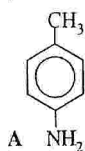


- 20.18 (1) That **A** reacts with benzenesulfonyl chloride in aqueous KOH to give a clear solution, which on acidification yields a precipitate, shows that **A** is a primary amine.
- (2) That diazotization of **A** followed by treatment with 2-naphthol gives an intensely colored precipitate shows that **A** is a primary aromatic amine; that is, **A** is a substituted aniline.
- (3) Consideration of the molecular formula of **A** leads us to conclude that **A** is a methylaniline (i.e., a toluidine).

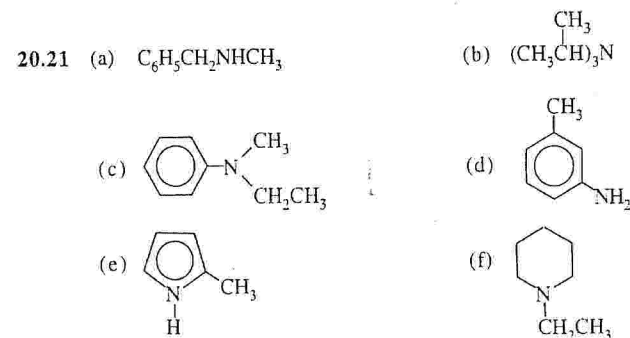
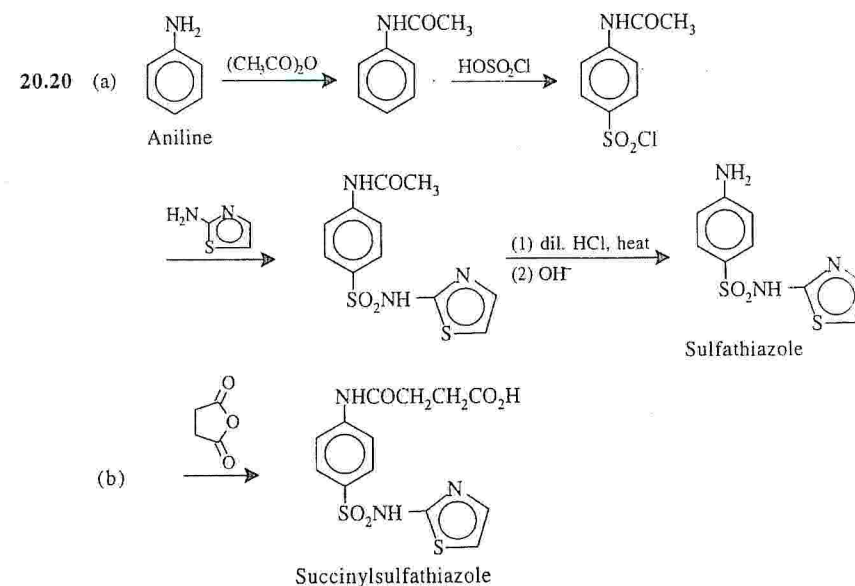
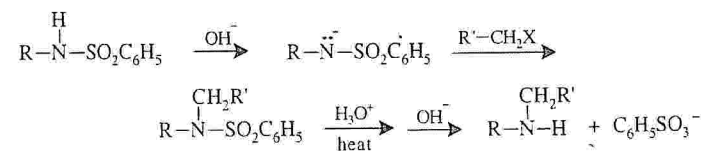


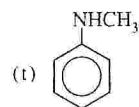
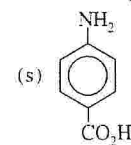
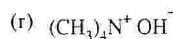
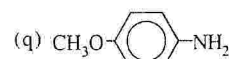
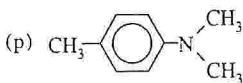
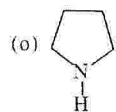
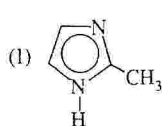
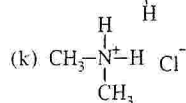
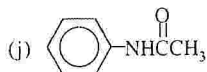
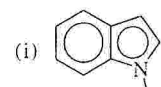
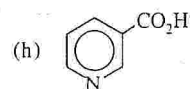
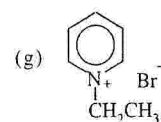
But is **A** 2-methylaniline, 3-methylaniline, or 4-methylaniline?

- (4) This question is answered by the IR data. A single absorption peak in the 680–840  $\text{cm}^{-1}$  region at 815  $\text{cm}^{-1}$  is indicative of a para substituted benzene. Thus, **A** is 4-methylaniline (*p*-toluidine).

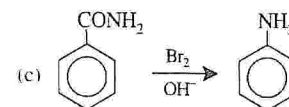
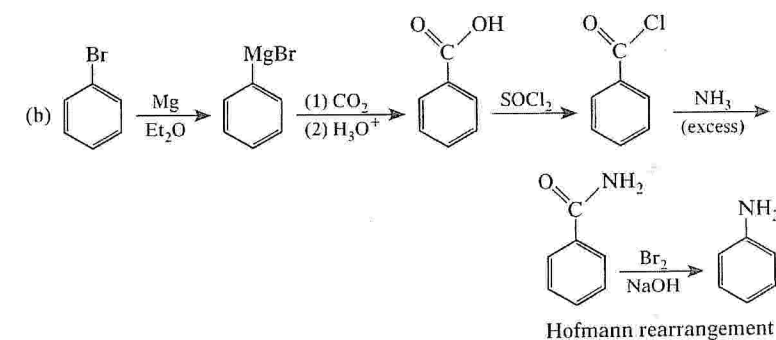
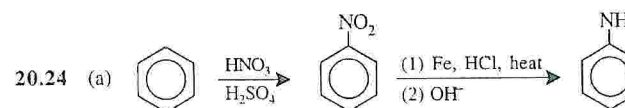
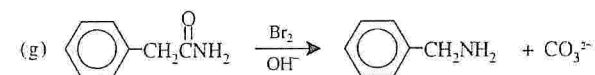
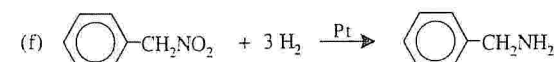
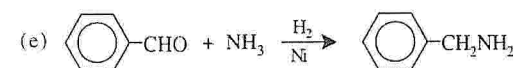
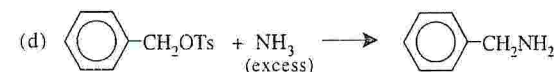
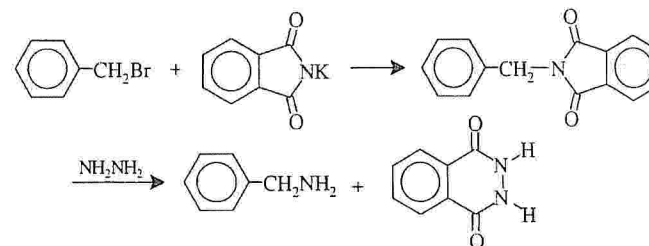
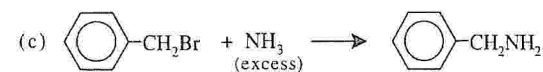
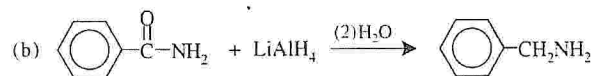
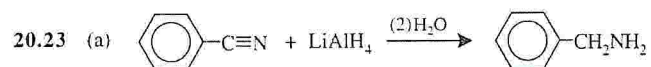


- 20.19 First convert the sulfonamide to its anion, then alkylate the anion with an alkyl halide, then remove the  $-\text{SO}_2\text{C}_6\text{H}_5$  group by hydrolysis. For example,

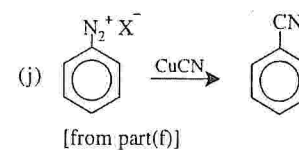
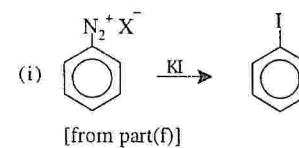
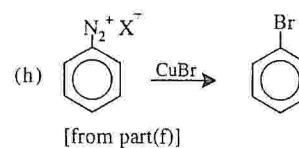
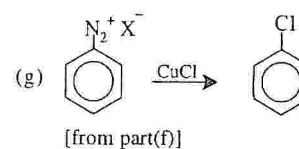
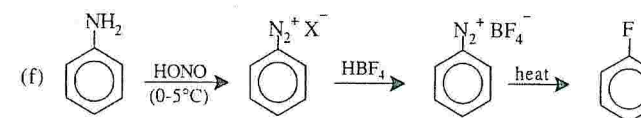
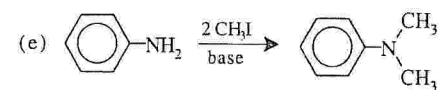
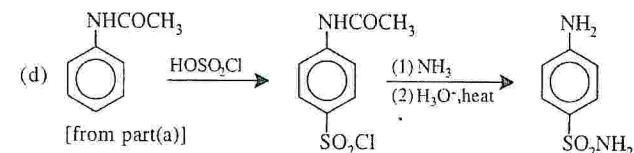
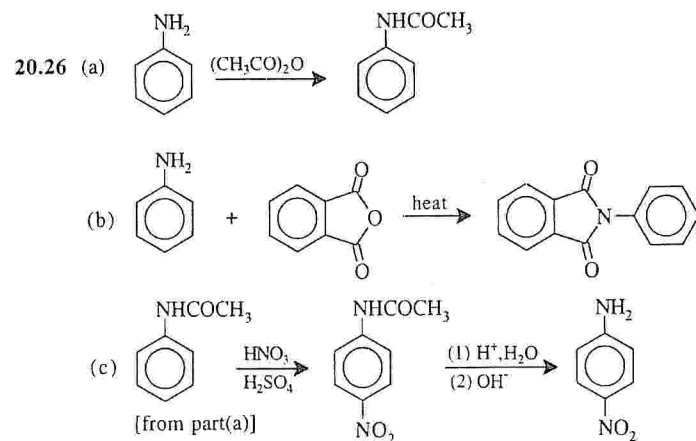
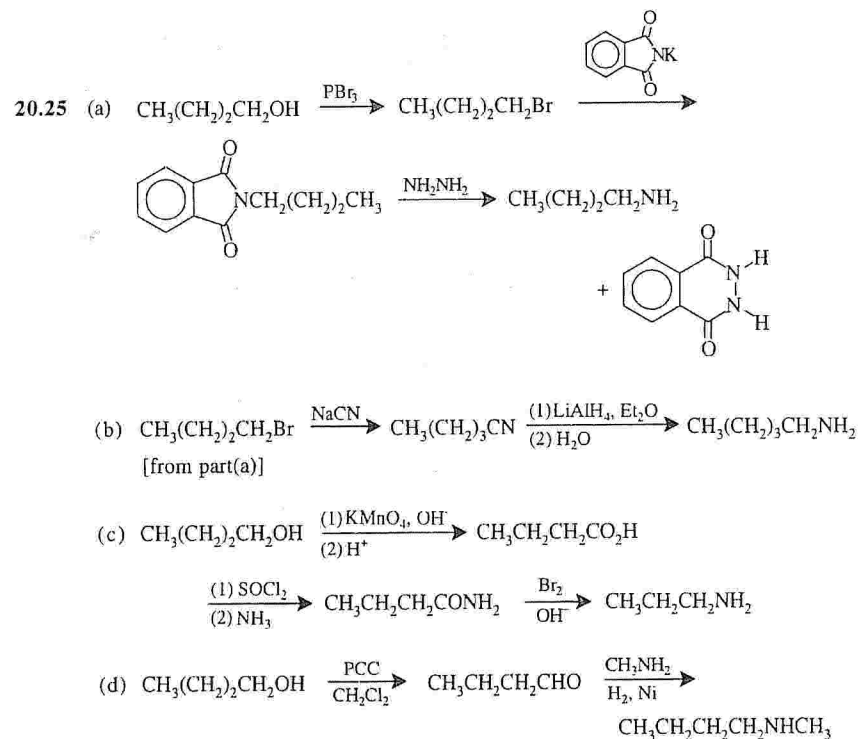


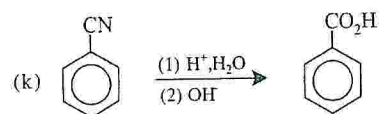


- 20.22 (a) Propylamine (h) Benzylaminium chloride  
 (b) *N*-Methylaniline (i) *N,N*-Dipropylaniline  
 (c) Isopropyltrimethylammonium iodide (j) Benzenesulfonamide  
 (d) 2-Methylaniline (*o*-toluidine) (k) Methylaminium acetate  
 (e) 2-Methoxyaniline (or *o*-methoxyaniline) (l) 3-Amino-1-propanol  
 (f) Pyrazole (m) Purine  
 (g) 2-Aminopyrimidine (n) *N*-Methylpyrrole

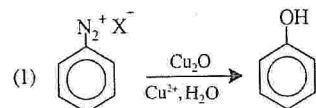




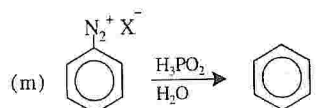




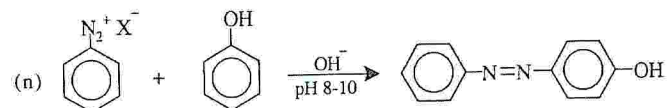
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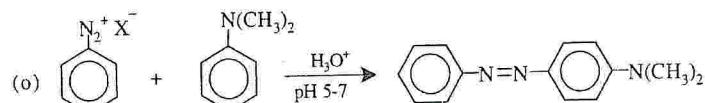
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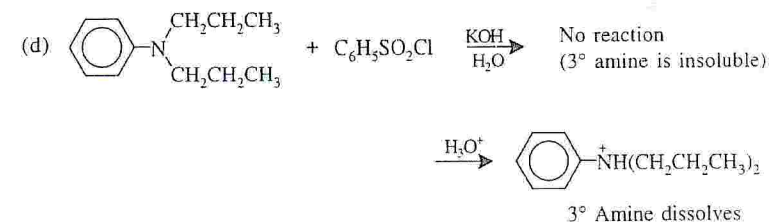
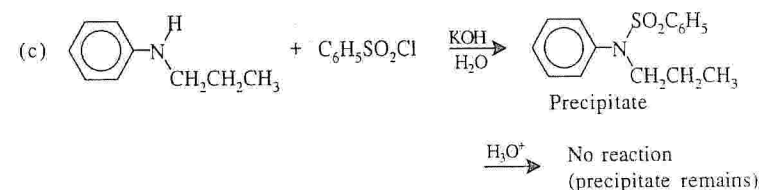
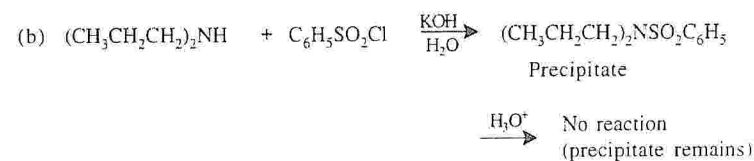
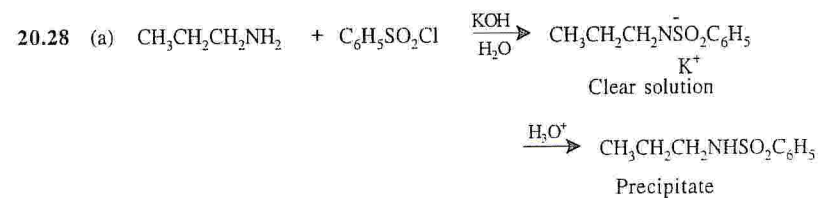
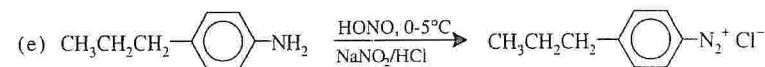
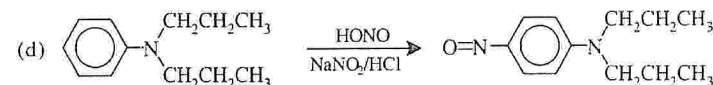
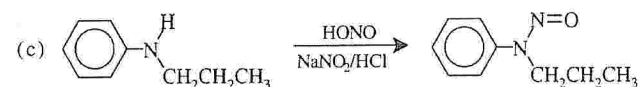
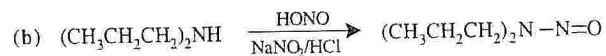
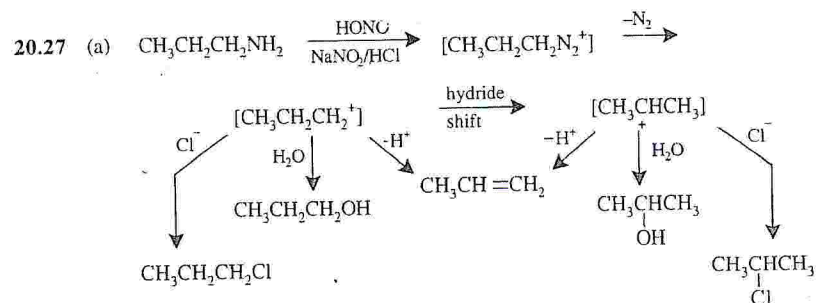
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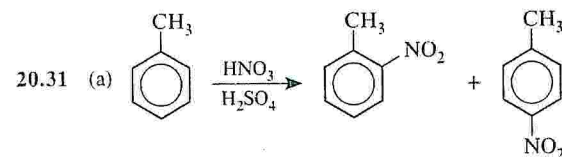
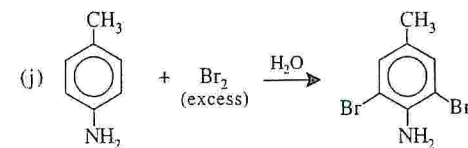
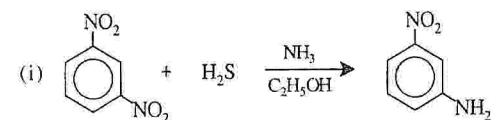
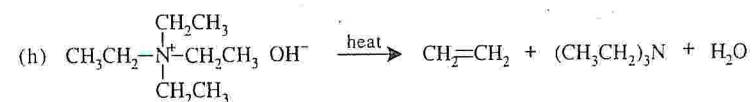
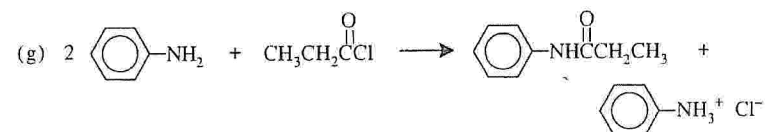
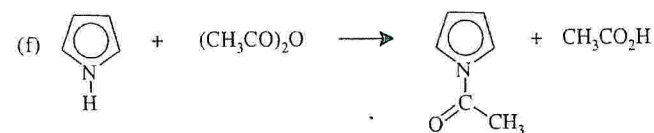
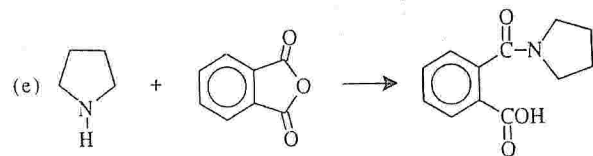
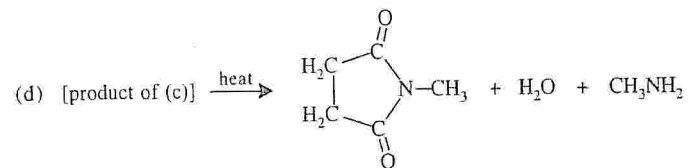
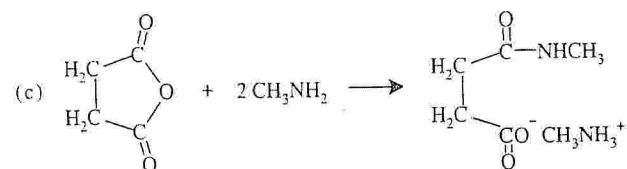
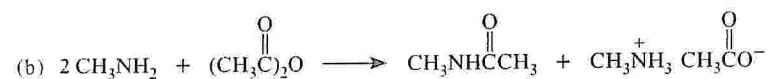
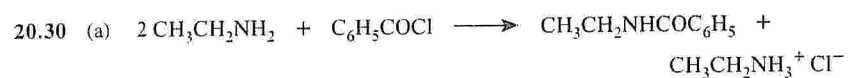
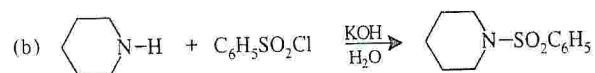
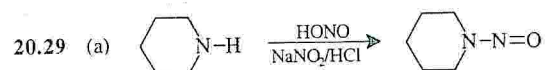
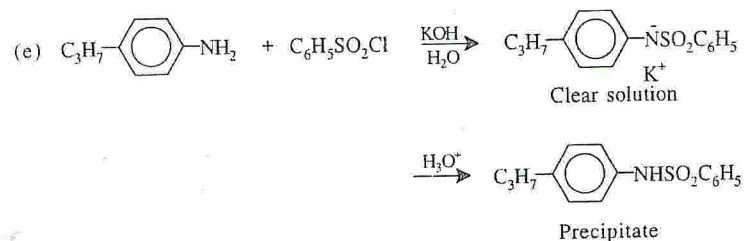


[from part(f)] [from part(l)]

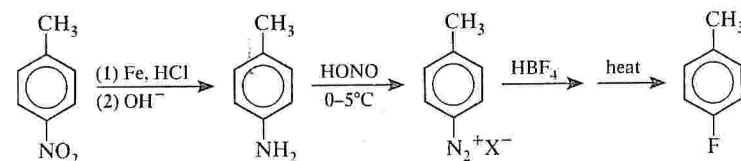


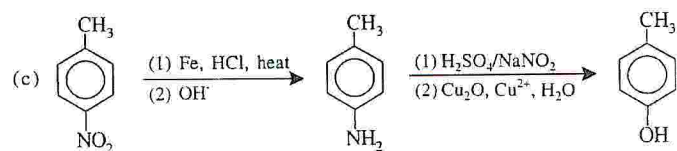
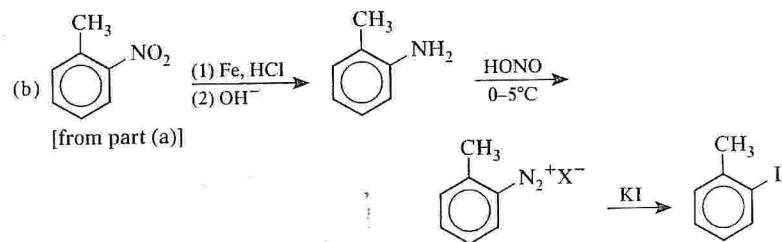
[from part(f)] [from part(e)]



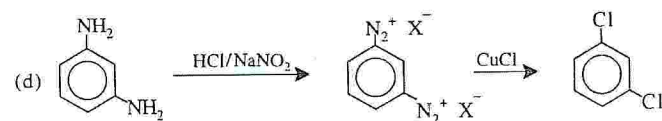
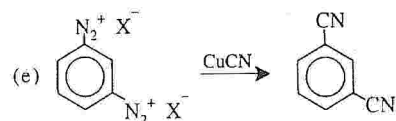


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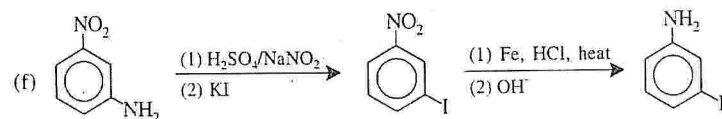




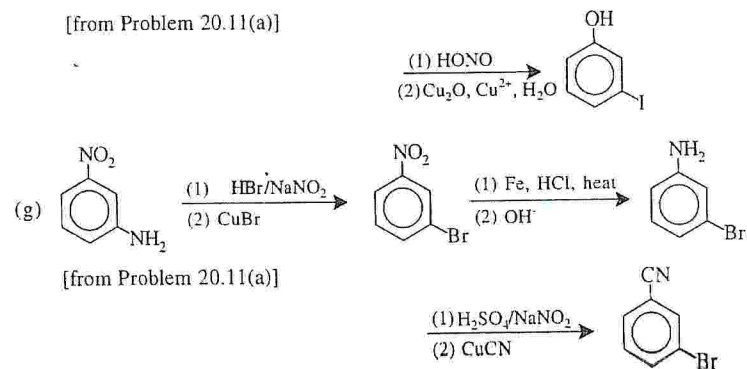
[from part (a)]

[by reduction of *m*-dinitrobenzene,  
cf. Problem 20.11(a)]

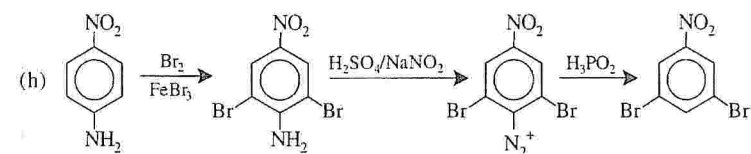
[from part (d)]



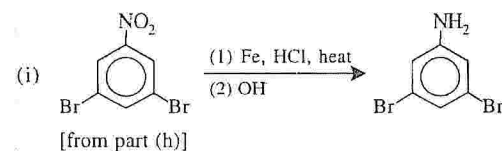
[from Problem 20.11(a)]



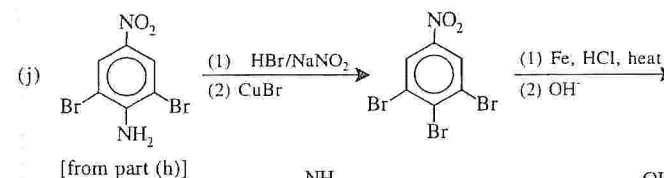
[from Problem 20.11(a)]



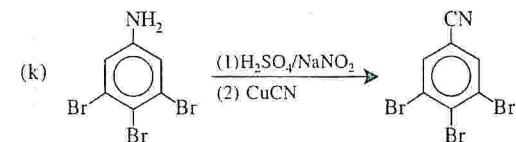
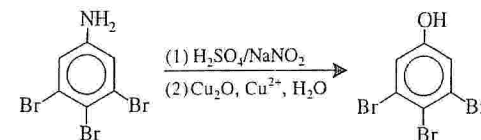
[from Problem 20.11(e)]



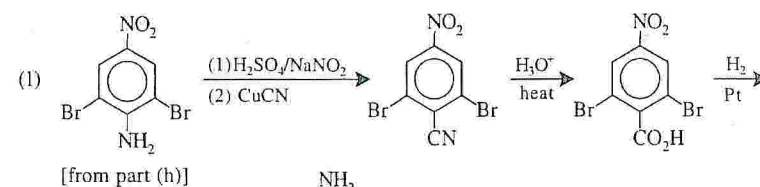
[from part (h)]



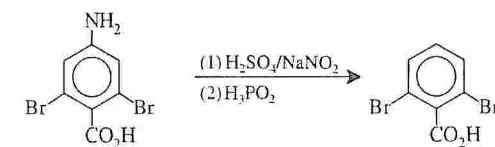
[from part (h)]



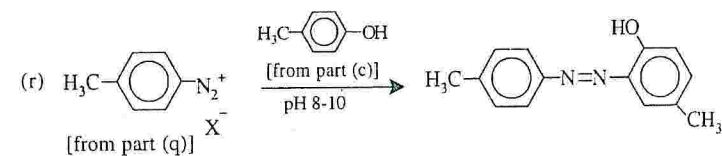
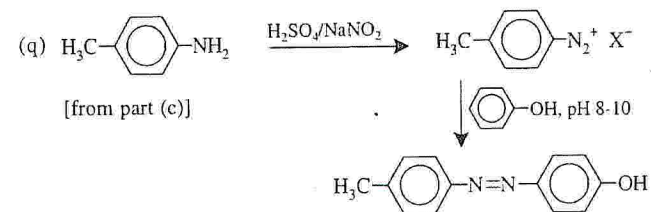
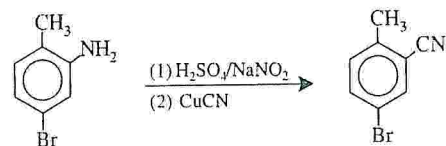
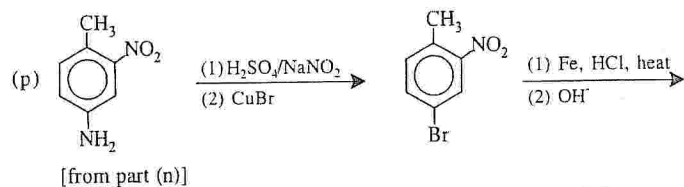
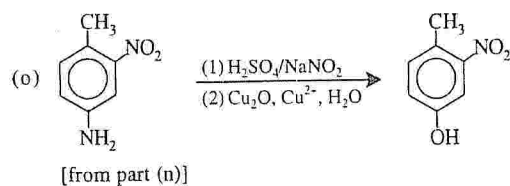
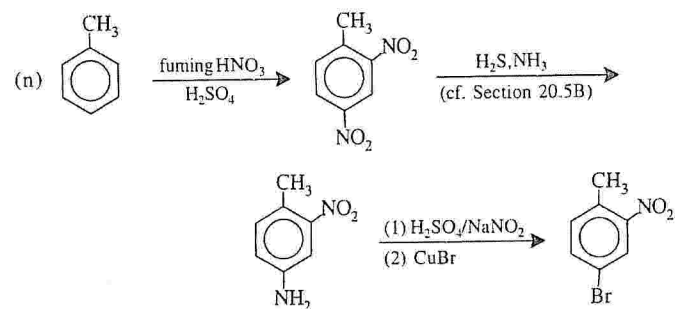
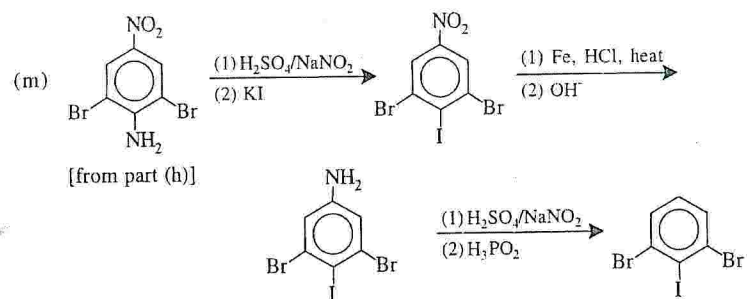
[from part (j)]



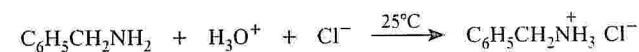
[from part (h)]



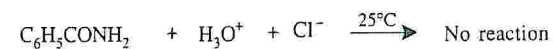




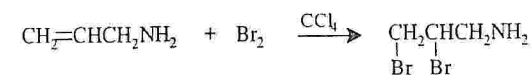
20.32 (a) Benzylamine dissolves in dilute HCl at room temperature,



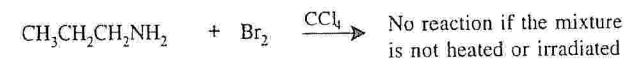
benzamide does not dissolve:



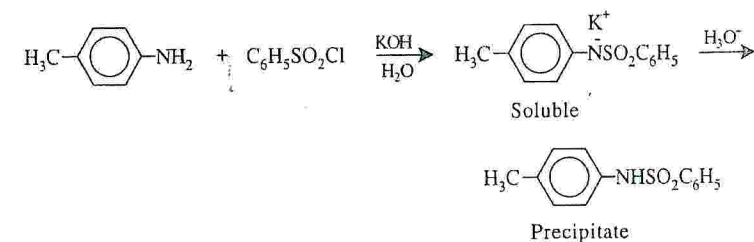
(b) Allylamine reacts with (and decolorizes) bromine in carbon tetrachloride instantly.

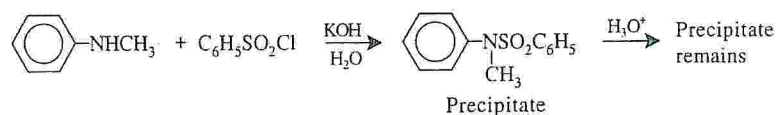


propylamine does not:

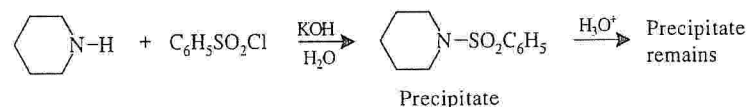
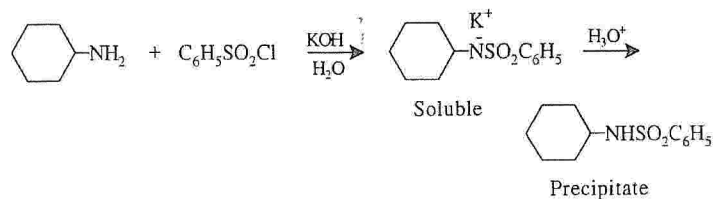


(c) The Hinsberg test:

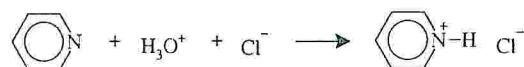




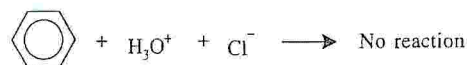
(d) The Hinsberg test:



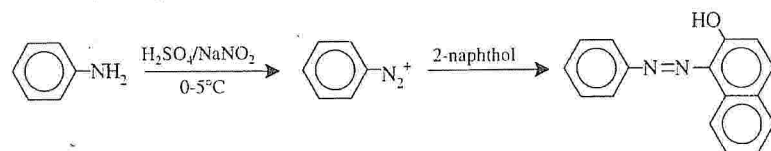
(e) Pyridine dissolves in dilute HCl.



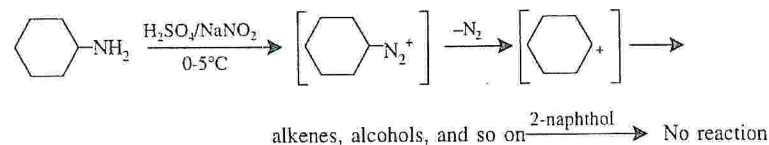
benzene does not:



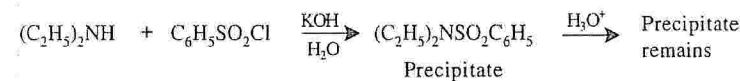
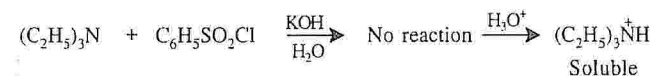
(f) Aniline reacts with nitrous acid at 0–5°C to give a stable diazonium salt that couples with 2-naphthol, yielding an intensely colored azo compound.



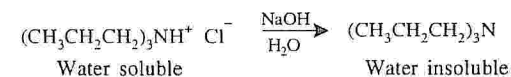
Cyclohexylamine reacts with nitrous acid at 0–5°C to yield a highly unstable diazonium salt—one that decomposes so rapidly that the addition of 2-naphthol gives no azo compound.



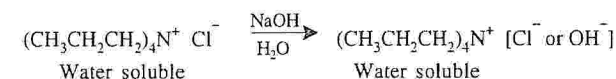
(g) The Hinsberg test:



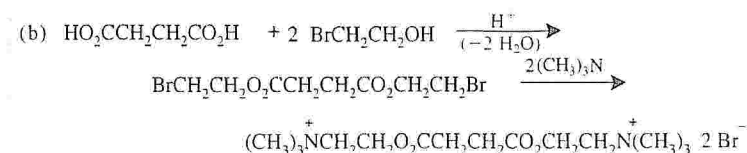
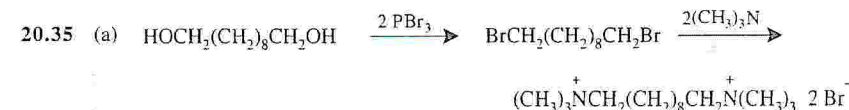
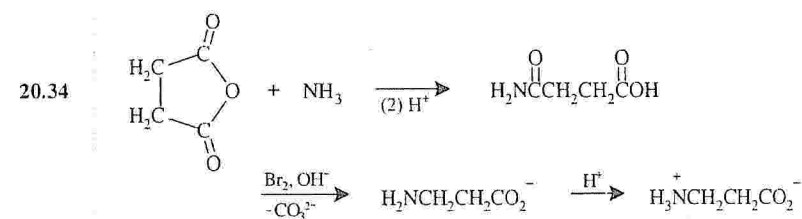
(h) Tripropylammonium chloride reacts with aqueous NaOH to give a water insoluble tertiary amine.

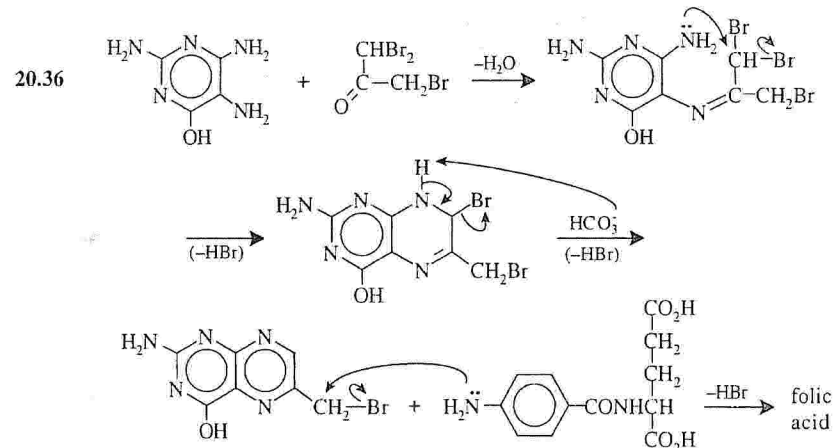


Tetrapropylammonium chloride does not react with aqueous NaOH (at room temperature), and the tetrapropylammonium ion remains in solution.



(i) Tetrapropylammonium chloride dissolves in water to give a neutral solution. Tetrapropylammonium hydroxide dissolves in water to give a strongly basic solution.

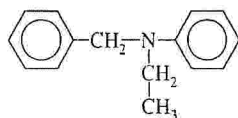
**20.33** Follow the procedure outlined in the answer to Problem 20.2. Toluene will show the same solubility behavior as benzene.



20.37 The results of the Hinsberg test indicate that compound **W** is a tertiary amine. The  $^1\text{H}$  NMR provides evidence for the following:

- (1) Two different  $\text{C}_6\text{H}_5$ -groups (one absorbing at  $\delta$  7.2 and one at  $\delta$  6.7).
- (2) A  $\text{CH}_3\text{CH}_2$ -group (the quartet at  $\delta$  3.5 and the triplet at  $\delta$  1.2).
- (3) An unsplit  $-\text{CH}_2-$  group (the singlet at  $\delta$  4.5).

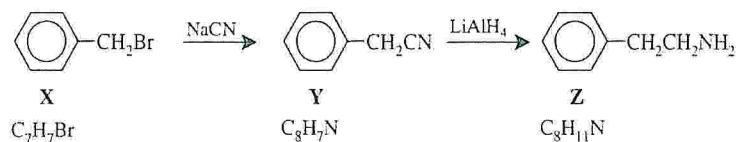
There is only one reasonable way to pull all of this together.



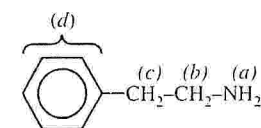
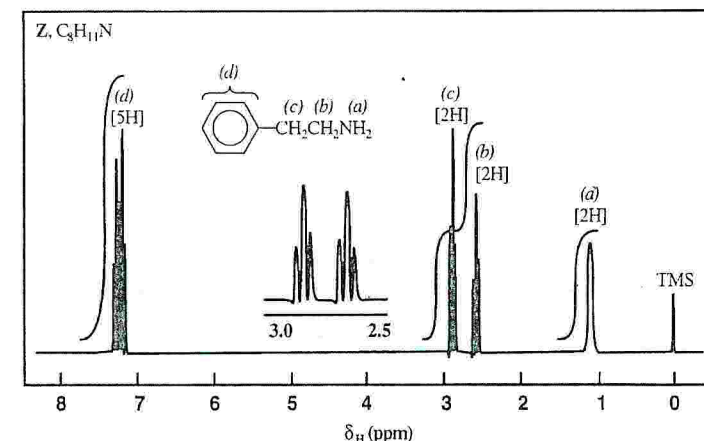
Thus **W** is *N*-benzyl-*N*-ethylaniline.

20.38 Compound **X** is benzyl bromide,  $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$ . This is the only structure consistent with the  $^1\text{H}$  NMR and IR data. (The monosubstituted benzene ring is strongly indicated by the (5H),  $\delta$  7.3  $^1\text{H}$  NMR absorption and is confirmed by the peaks at 690 and 770  $\text{cm}^{-1}$  in the IR spectrum.)

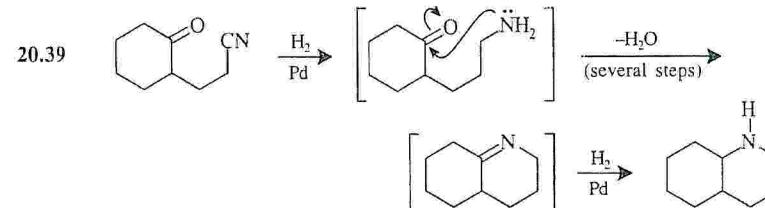
Compound **Y**, therefore, must be phenylacetonitrile, ( $\text{C}_6\text{H}_5\text{CH}_2\text{CN}$ ) and **Z** must be 2-phenylethylamine,  $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}_2$ .

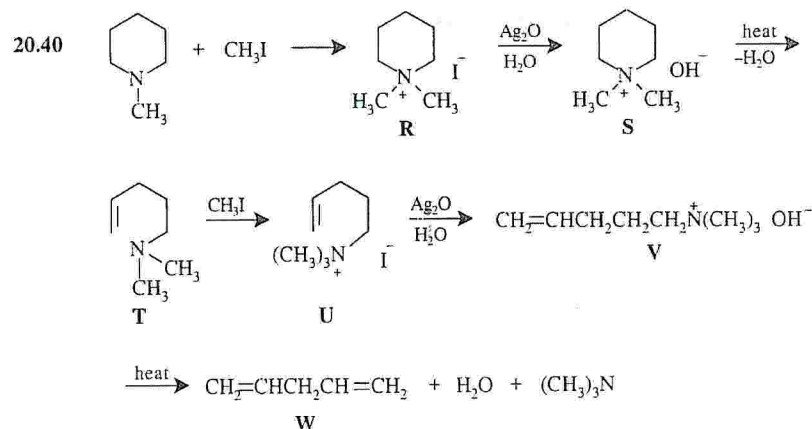


Interpretations of the IR and  $^1\text{H}$  NMR spectra of **Z** are as follows.

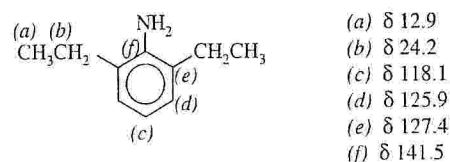


- (a) singlet  $\delta$  1.0  
 (b) triplet  $\delta$  2.7  
 (c) triplet  $\delta$  2.9  
 (d) multiplet  $\delta$  7.25



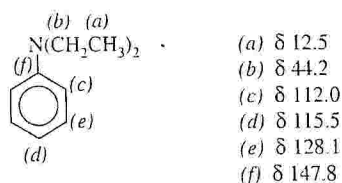


- 20.41 That **A** contains nitrogen and is soluble in dilute HCl suggests that **A** is an amine. The two IR absorption bands in the 3300–3500-cm<sup>-1</sup> region suggest that **A** is a primary amine. The <sup>13</sup>C spectrum shows only two signals in the upfield aliphatic region. There are four signals downfield in the aromatic region. The information from the DEPT spectra suggests an ethyl group or two equivalent ethyl groups. Assuming the latter, and assuming that **A** is a primary amine, we can conclude from the molecular formula that **A** is 2,6-diethylaniline. The assignments are



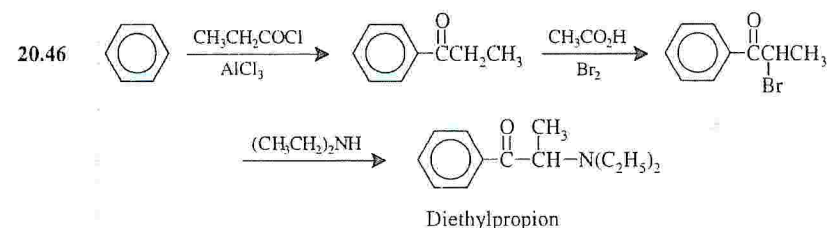
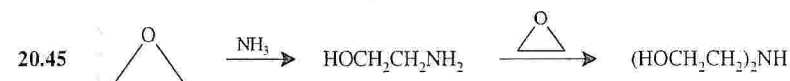
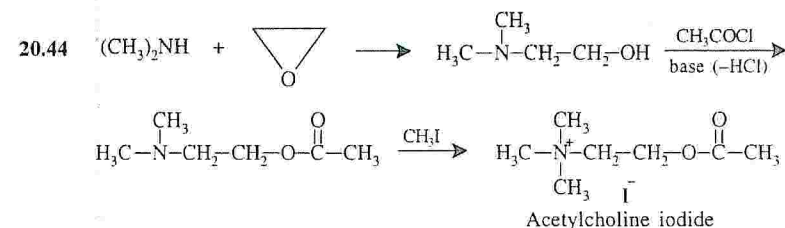
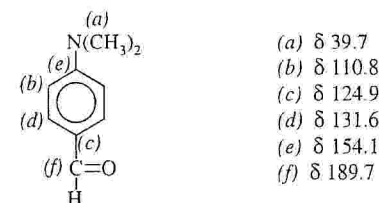
(An equally plausible answer would be that **A** is 3,5-diethylaniline.)

- 20.42 That **B** dissolves in dilute HCl suggests that **B** is an amine. That the IR spectrum of **B** lacks bands in the 3300–3500-cm<sup>-1</sup> region suggests that **B** is a tertiary amine. The upfield signals in the <sup>13</sup>C spectrum and the DEPT information suggest two equivalent ethyl groups (as was also true of **A** in the preceding problem). The DEPT information for the downfield peaks (in the aromatic region) is consistent with a monosubstituted benzene ring. Putting all of these observations together with the molecular formula leads us to conclude that **B** is *N,N*-diethylaniline. The assignments are



- 20.43 That **C** gives a positive Tollens' test indicates the presence of an aldehyde group; the solubility of **C** in aqueous HCl suggests that **C** is also an amine. The absence of bands in the 3300–3500-cm<sup>-1</sup> region of the IR spectrum of **C** suggests that **C** is a tertiary amine. The signal at  $\delta$  189.7 in the <sup>13</sup>C spectrum can be assigned to the aldehyde group. The signal at  $\delta$  39.7 is the only one in the aliphatic region and is consistent with a methyl group or with two equivalent methyl groups. The remaining signals are in the aromatic region. If we assume that **C**

has a benzene ring containing a -CH group and a -N(CH<sub>3</sub>)<sub>2</sub> group, then the aromatic signals and their DEPT spectra are consistent with **C** being *p*-(*N,N*-dimethylamino)benzaldehyde. The assignments are

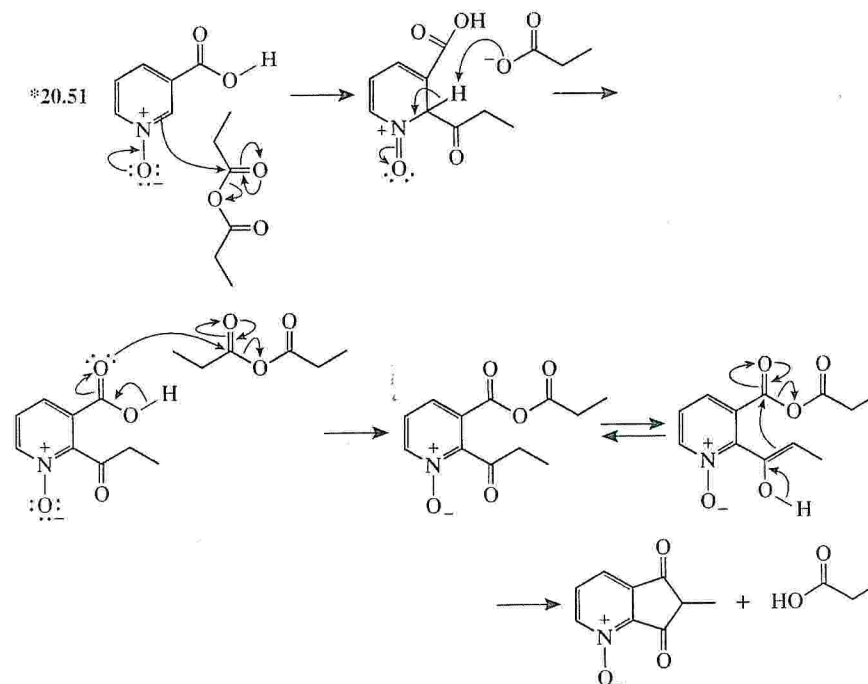
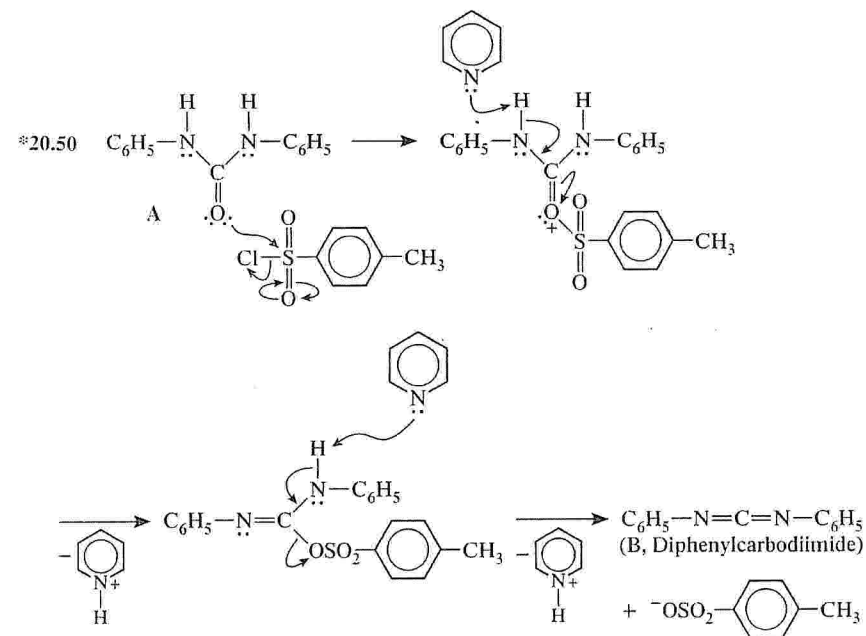
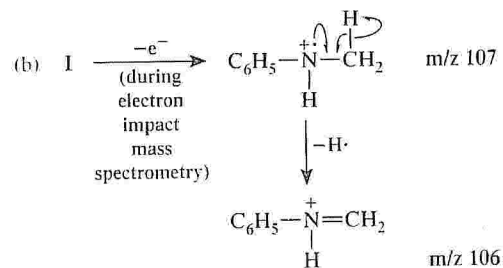
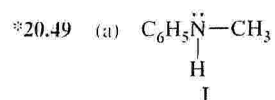
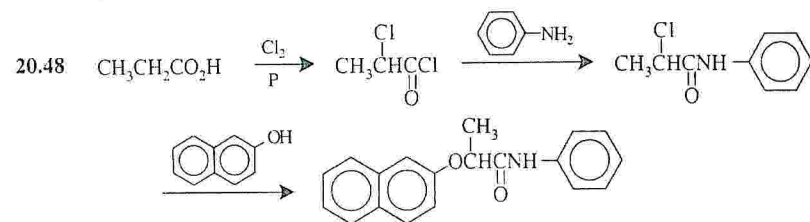




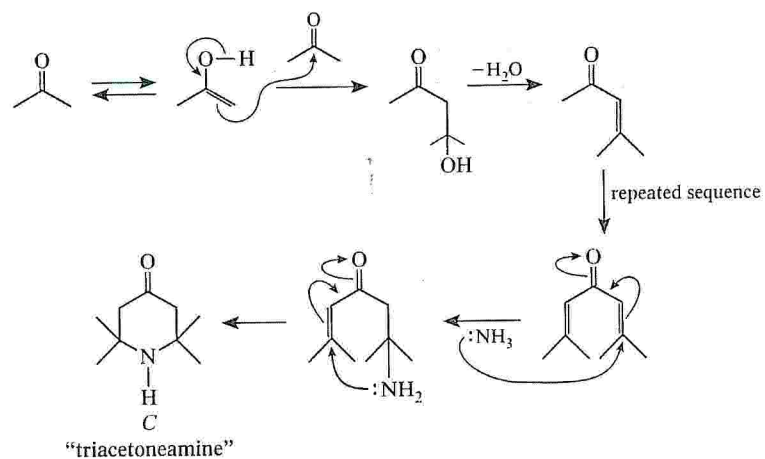
**20.47** Carry out the Hofmann reaction using a mixture of  $^{15}\text{N}$  labeled benzamide,  $\text{C}_6\text{H}_5\text{CO}^*\text{NH}_2$ , and *p*-chlorobenzamide. If the process is intramolecular, only labeled aniline,  $\text{C}_6\text{H}_5^*\text{NH}_2$ , and *p*-chloroaniline, will be produced.

If the process is one, in addition to the two products mentioned above, there should be produced both the unlabeled aniline and labeled *p*-chloroaniline,  $p\text{-ClC}_6\text{H}_4^*\text{NH}_2$ .

Note: When this experiment is actually carried out, analysis of the reaction mixture by mass spectrometry shows that the process is intramolecular.



\*20.52 An abbreviated version of one of several possible routes:



## QUIZ

20.1 Which of the following would be soluble in dilute aqueous HCl?

- (a)  $\text{C}_6\text{H}_5\text{NH}_2$
- (b)  $\text{C}_6\text{H}_5\text{CH}_2\text{NH}_2$
- (c)  $\text{C}_6\text{H}_5\text{CNH}_2$
- (d) Two of the above
- (e) All of the above

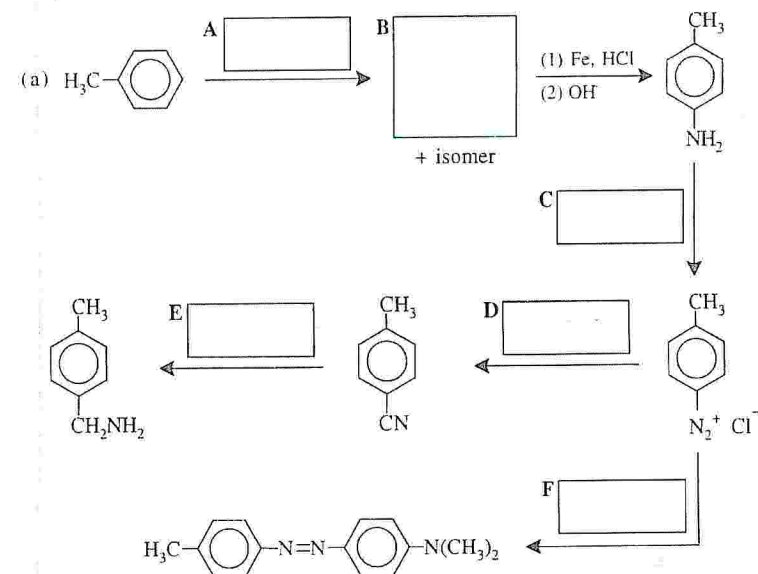
20.2 Which would yield propylamine?

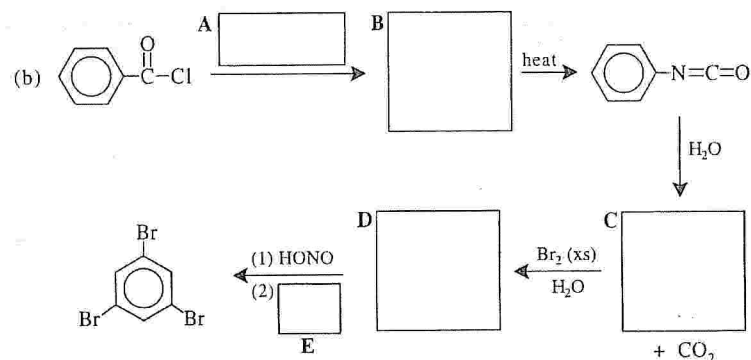
- (a)  $\text{CH}_3\text{CH}_2\text{Br} \xrightarrow{(1) \text{NaCN}} \xrightarrow{(2) \text{LiAlH}_4}$
- (b)  $\text{CH}_3\text{CH}_2\text{CHO} \xrightarrow{\text{NH}_3} \xrightarrow{\text{H}_2/\text{Ni}}$
- (c)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CONH}_2 \xrightarrow{\text{Br}_2} \xrightarrow{\text{OH}^-}$
- (d) Two of the above
- (e) All of the above

20.3 Select the reagent from the list below that could be the basis of a simple chemical test that would distinguish between each of the following:

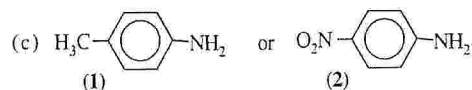
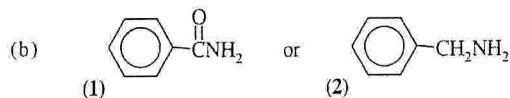
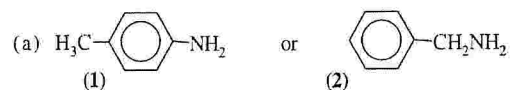
- (a)  $\text{C}_6\text{H}_5\text{CONH}_2$  and  $\text{C}_6\text{H}_5\text{CH}_2\text{NH}_2$
  - (b)  $\text{C}_6\text{H}_5\text{CH}_2\text{NH}_2$  and  $\text{C}_6\text{H}_5\text{NHCH}_3$
  - (c)  $\text{C}_6\text{H}_5\text{NH}_2$  and  $\text{C}_6\text{H}_{11}\text{NH}_2$
1. Cold dilute  $\text{NaHCO}_3$
  2. Cold dilute HCl
  3.  $\text{NaNO}_2$ , HCl,  $5^\circ\text{C}$ , then 2-naphthol
  4.  $\text{C}_6\text{H}_5\text{SO}_2\text{Cl}$ ,  $\text{OH}^-$ , then HCl
  5. Cold dilute NaOH

20.4 Complete the following syntheses:





20.5 Select the stronger base from each pair:

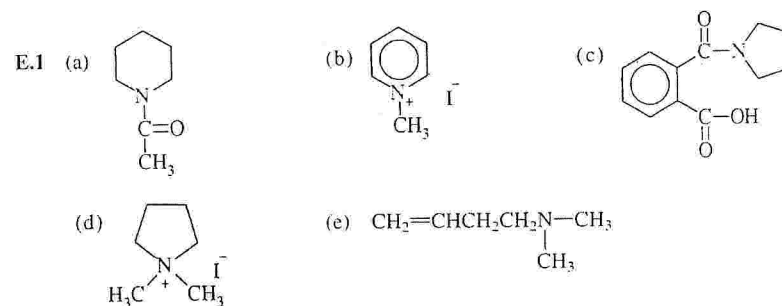


# E

## SPECIAL TOPIC

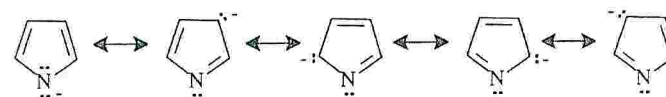
### Reactions and Synthesis of Heterocyclic Amines

## SOLUTIONS TO PROBLEMS

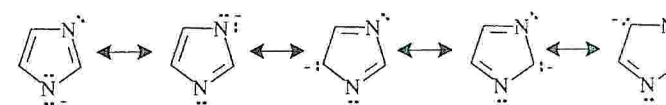


E.2 (a) The cyclopentadienyl anion.

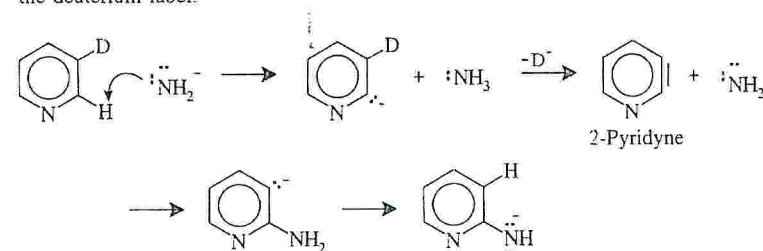
(b) The pyrrole anion is a resonance hybrid of the following structures:



The imidazole anion is a hybrid of these:

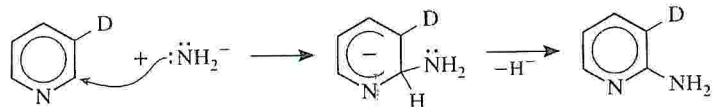


E.3 A mechanism involving a "pyridyne" intermediate would involve a net loss (of 50%) of the deuterium label.



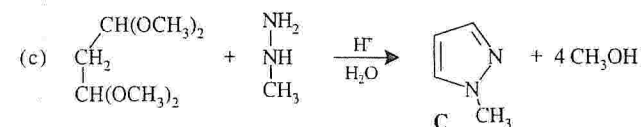
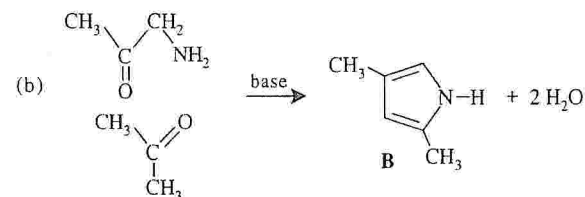
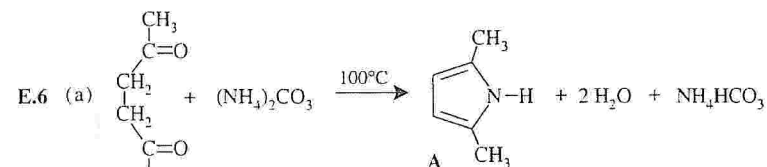
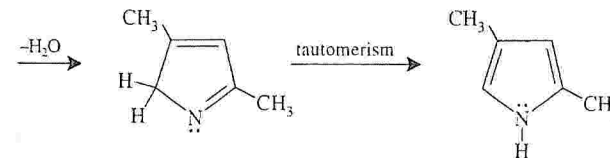
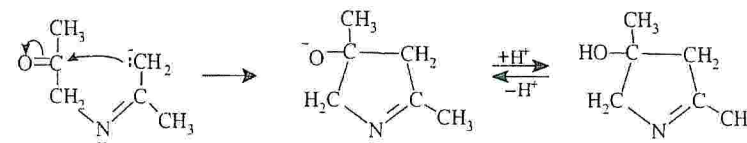
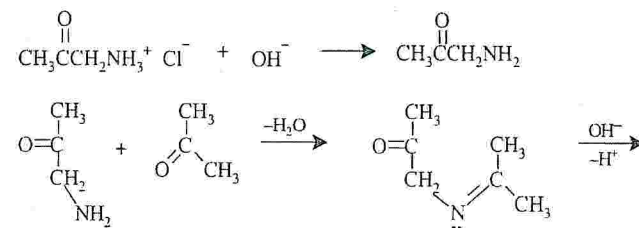
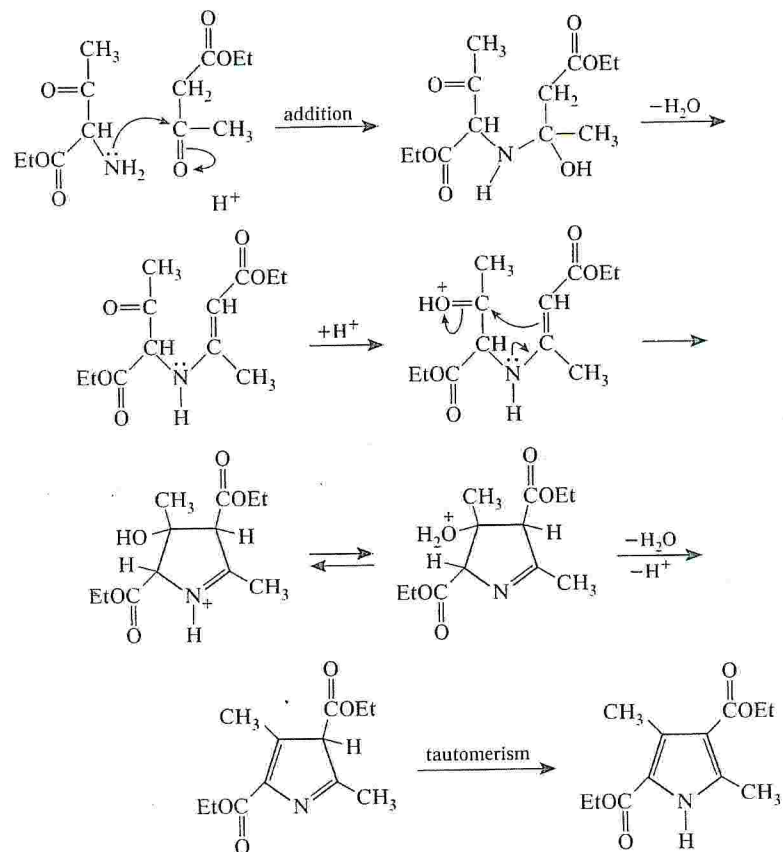
Since in the actual experiment there was no loss of deuterium, this mechanism was disallowed.

The mechanism given in Section E.4 would not be expected to result in a loss of deuterium; thus, it is consistent with the labeling experiment.

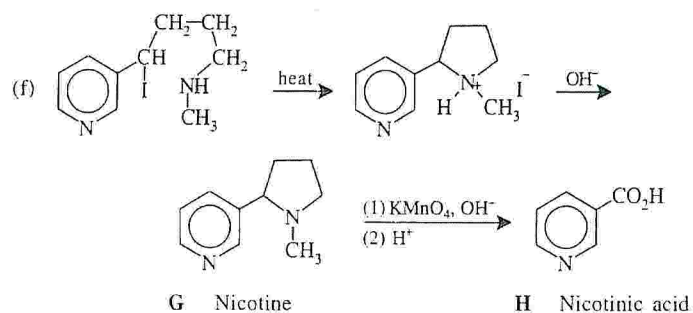
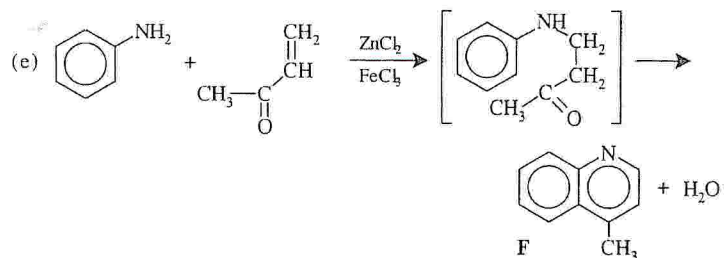
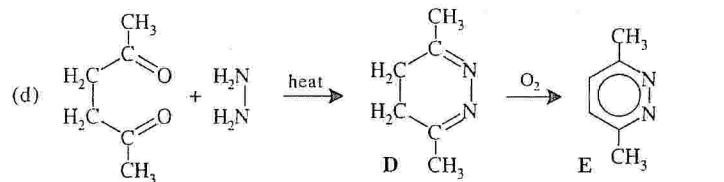


E.4 When pyridine undergoes nucleophilic substitution, the leaving group is a hydride ion—an ion that is a strong base and, consequently, a poor leaving group. With 2-halopyridines, on the other hand, the leaving groups are halide ions—ions that are weak bases and thus good leaving groups.

E.5 If we write the reactants in the following way, we can better see how the reaction occurs.





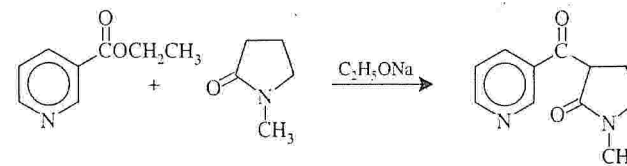


## F SPECIAL TOPIC

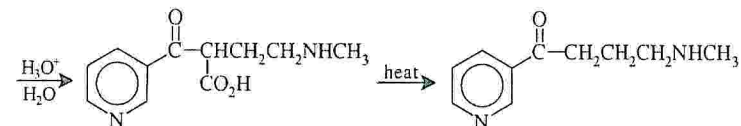
### Alkaloids

#### SOLUTIONS TO PROBLEMS

E.1 (a) The first step is similar to a crossed Claisen condensation (see Section 19.2A):

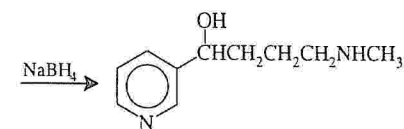


(b) This step involves hydrolysis of an amide (lactam) and can be carried out with either acid or base. Here we use acid.

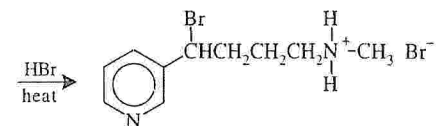


(c) This step is the decarboxylation of a substituted malonic acid; it requires only the application of heat and takes place during the acid hydrolysis of step (b).

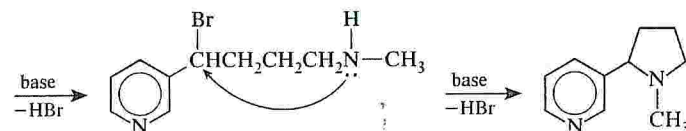
(d) This is the reduction of a ketone to a secondary alcohol. A variety of reducing agents can be used, sodium borohydride, for example.



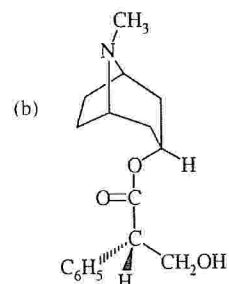
(e) Here we convert the secondary alcohol to an alkyl bromide with hydrogen bromide; this reagent also gives a hydrobromide salt of the aliphatic amine.



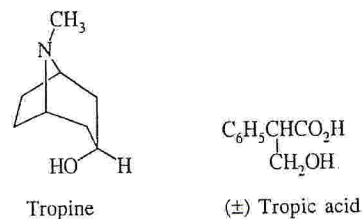
(f) Treating the salt with base produces the secondary amine; it then acts as a nucleophile and attacks the carbon atom bearing the bromine. This reaction leads to the formation of a five-membered ring and ( $\pm$ ) nicotine.



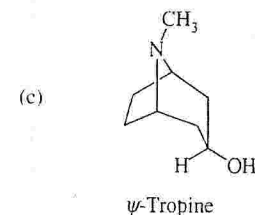
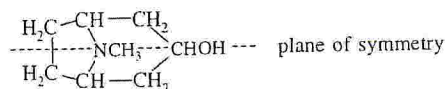
F.2 (a) The stereocenter adjacent to the ester carbonyl group is racemized by base (probably through the formation of an anion that can undergo inversion of configuration; cf. Section 17.3).



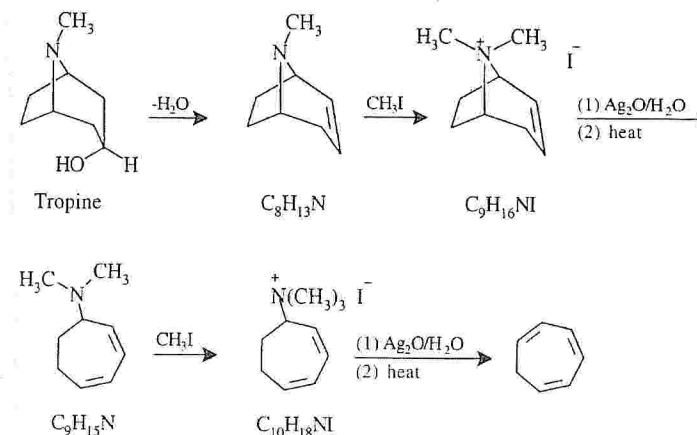
F.3 (a)



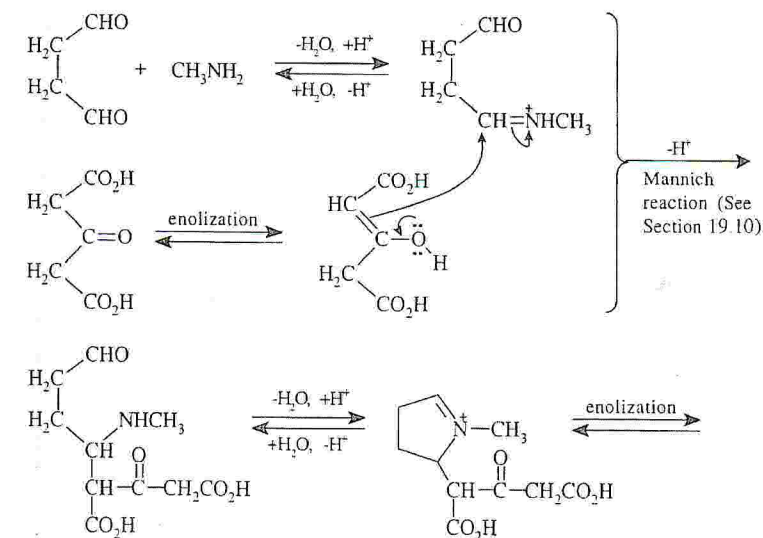
(b) Tropine is a meso compound; it has a plane of symmetry that passes through the  $\text{CHOH}$  group, the  $\text{NCH}_3$  group, and between the two  $\text{-CH}_2\text{-}$  groups of the five-membered ring.

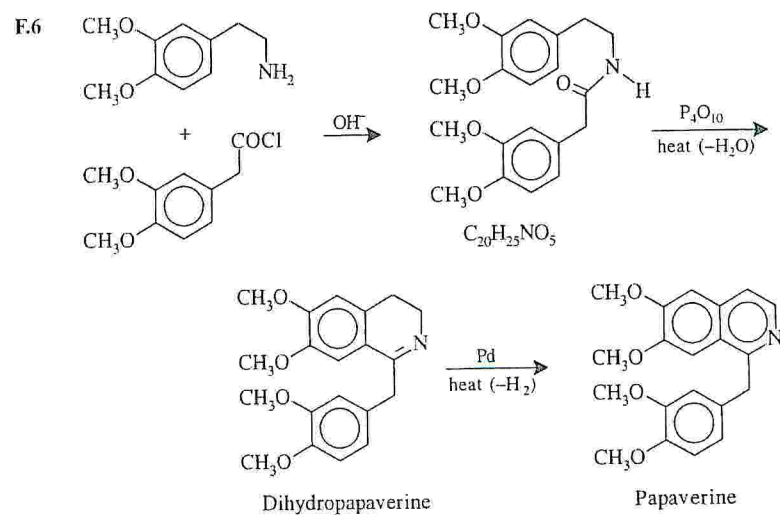
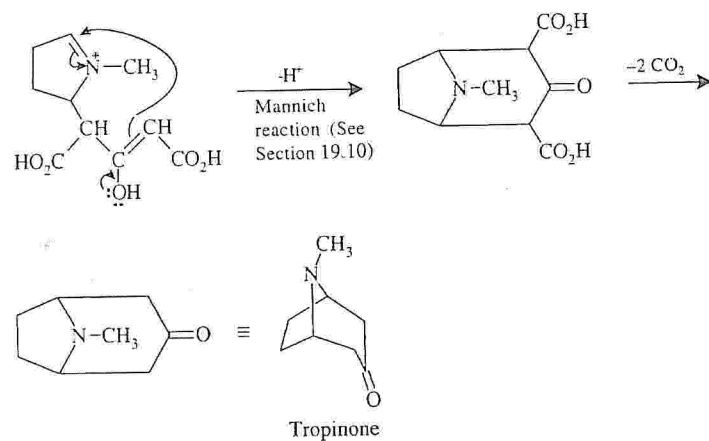


F.4

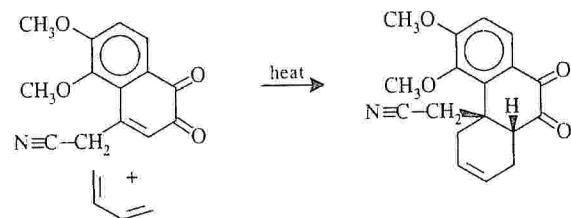


F.5 One possible sequence of steps is the following:

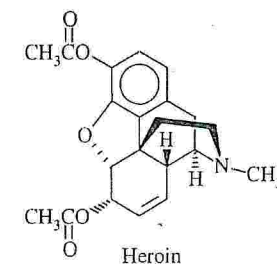




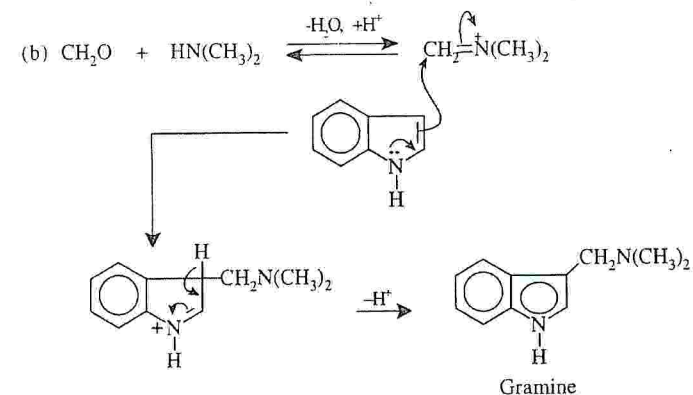
E7 A Diels-Alder reaction was carried out using 1,3-butadiene as the diene component.



F.8 Acetic anhydride acetylates both  $-OH$  groups.

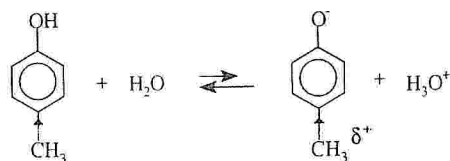


**F.9** (a) A Mannich reaction (see Section 19.10).



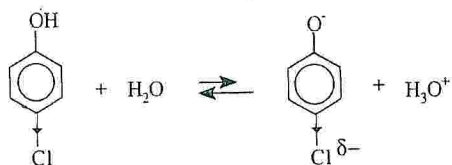
## SOLUTIONS TO PROBLEMS

- 21.1** An electron-releasing group (i.e.,  $-\text{CH}_3$ ) changes the charge distribution in the molecule so as to make the hydroxyl oxygen less positive, causing the proton to be held more strongly; it also destabilizes the phenoxide anion by intensifying its negative charge. These effects make the substituted phenol less acidic than phenol itself.



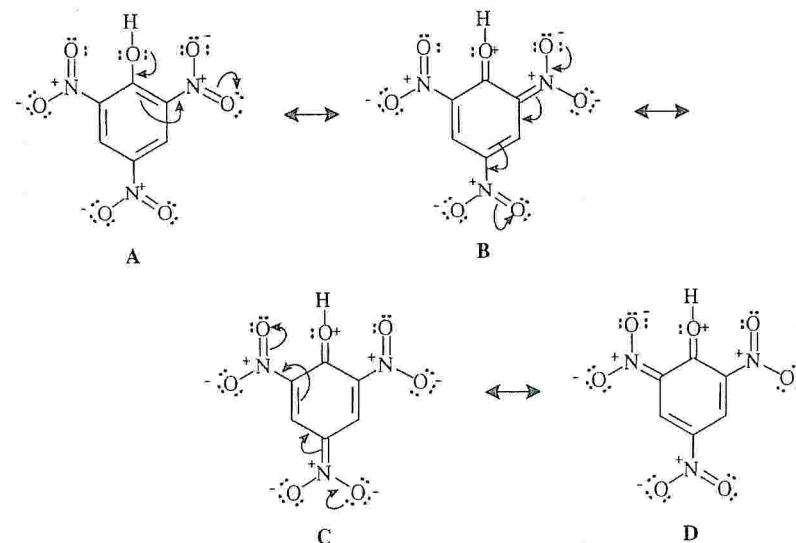
Electron-releasing  $-\text{CH}_3$  destabilizes the anion more than the acid— $\text{p}K_a$  is larger than for phenol.

- 21.2** An electron-withdrawing group such as chlorine changes the charge distribution in the molecule so as to make the hydroxyl oxygen more positive, causing the proton to be held less strongly; it also can stabilize the phenoxide ion by dispersing its negative charge. These effects make the substituted phenol more acidic than phenol itself.



Electron-withdrawing chlorine stabilizes the anion by dispersing the negative charge.  $\text{p}K_a$  is smaller than for phenol.

Nitro groups are very powerful electron-withdrawing groups by their inductive and resonance effects. Resonance structures (B–D) below place a positive charge on the hydroxyl oxygen. This effect makes the hydroxyl oxygen dramatically more positive, causing the proton to be held much less strongly. These contributions explain why 2,4,6-trinitrophenol (picric acid) is so exceptionally acidic.



- 21.3** Dissolve the mixture in a solvent such as  $\text{CH}_2\text{Cl}_2$  (one that is immiscible with water). Using a separatory funnel, extract this solution with an aqueous solution of sodium bicarbonate. This extraction will remove the benzoic acid from the  $\text{CH}_2\text{Cl}_2$  solution and transfer it (as a sodium benzoate) to the aqueous bicarbonate solution. Acidification of this aqueous extract will cause benzoic acid to precipitate; it can then be separated by filtration and purified by recrystallization.

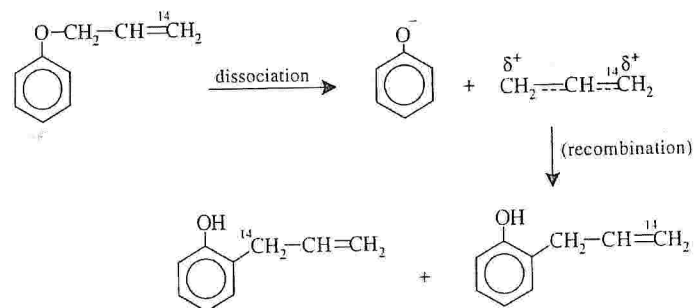
The  $\text{CH}_2\text{Cl}_2$  solution can now be extracted with an aqueous solution of sodium hydroxide. This will remove the 4-methylphenol (as its sodium salt). Acidification of the aqueous extract will cause the formation of 4-methylphenol as a water-insoluble layer. The 4-methylphenol can then be extracted into ether, the ether removed, and the 4-methylphenol purified by distillation.

The  $\text{CH}_2\text{Cl}_2$  solution will now contain only toluene (and  $\text{CH}_2\text{Cl}_2$ ). These can be separated easily by fractional distillation.

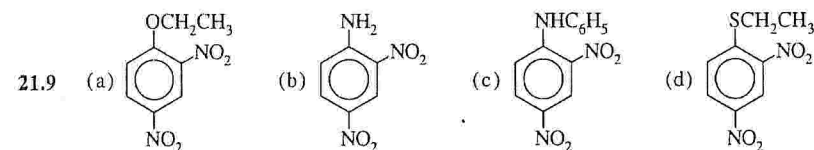
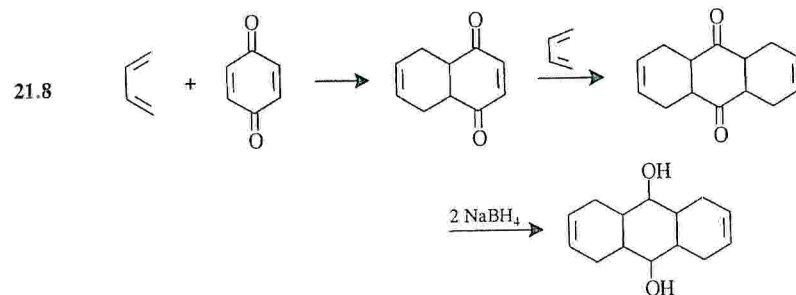
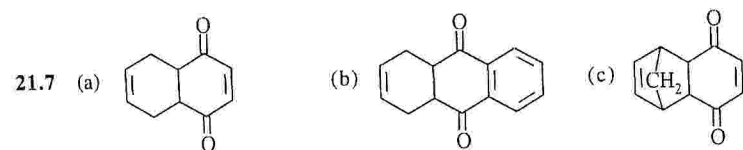
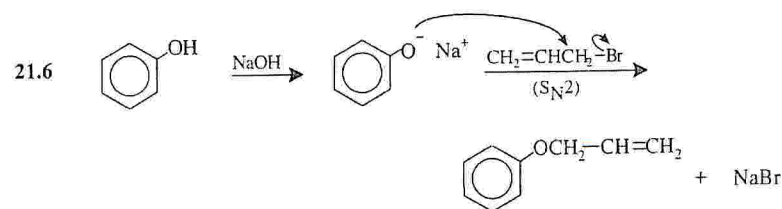
- 21.4** (a) The para-sulfonated phenol, because it is the major product at the higher temperature—when the reaction is under equilibrium control.  
(b) For ortho sulfonation, because it is the major reaction pathway at the lower temperature—when the reaction is under rate control.



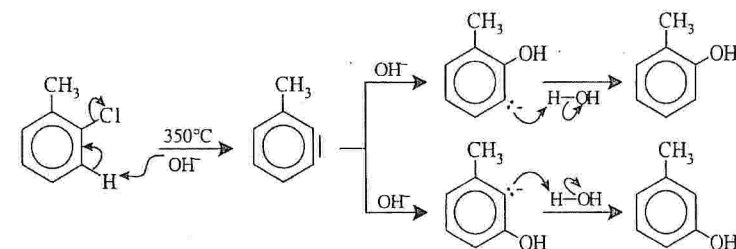
- 21.5 If the mechanism involved dissociation into an allyl cation and a phenoxide ion, then recombination would lead to two products: one in which the labeled carbon atom is bonded to the ring and one in which an unlabeled carbon atom is bonded to the ring.



The fact that all of the product has the labeled carbon atom bonded to the ring eliminates this mechanism from consideration.

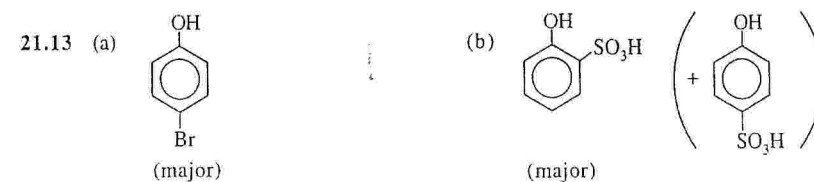
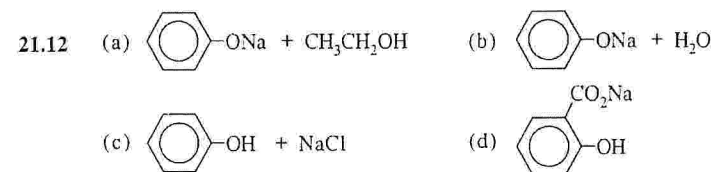


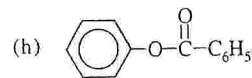
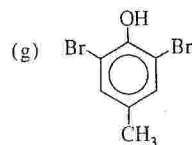
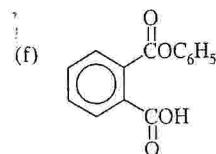
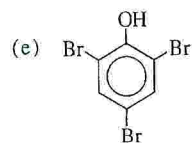
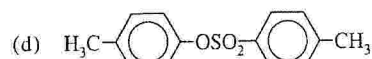
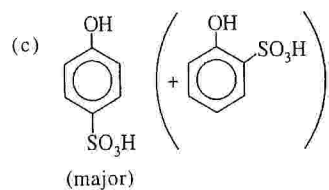
- 21.10 That *o*-chlorotoluene leads to the formation of two products (*o*-cresol and *m*-cresol) when submitted to the conditions used in the Dow process suggests that an elimination-addition mechanism takes place.



Inasmuch as chlorobenzene and *o*-chlorotoluene should have similar reactivities under these conditions, it is reasonable to assume that chlorobenzene reacts by an elimination-addition mechanism in the Dow process.

- 21.11 2-Bromo-1,3-dimethylbenzene, because it has no  $\alpha$ -hydrogen, cannot undergo an elimination. Its lack of reactivity toward sodium amide in liquid ammonia suggests that those compounds (e.g., bromobenzene) that do react do so by a mechanism that begins with an elimination.

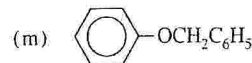




(i) Same as (h)

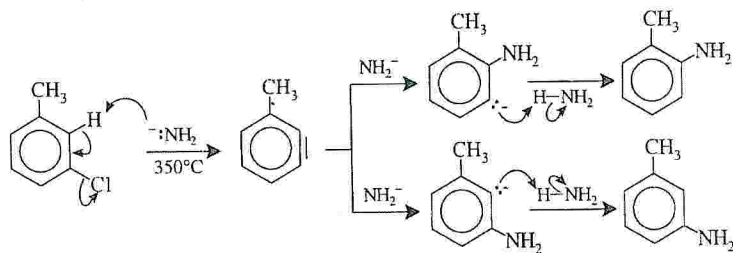


(l) Same as (k)

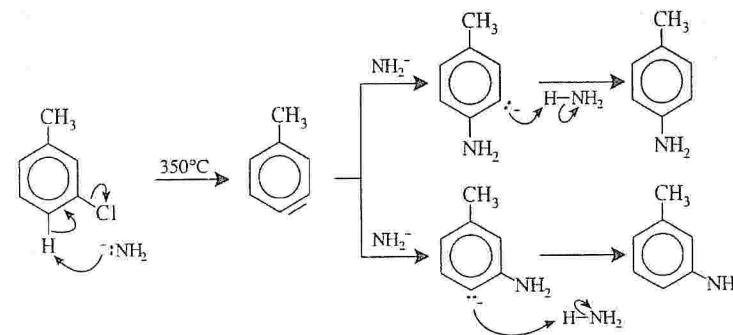


- 21.14 (a) 4-Chlorophenol will dissolve in aqueous NaOH; 4-chloro-1-methylbenzene will not.  
 (b) 4-Methylbenzoic acid will dissolve in aqueous  $\text{NaHCO}_3$ ; 4-methylphenol will not.  
 (c) Phenyl vinyl ether will react with bromine in carbon tetrachloride by addition (thus decolorizing the solution); ethyl phenyl ether will not.  
 (d) 2,4,6-Trinitrophenol, because it is so exceptionally acidic ( $\text{p}K_a = 0.38$ ), will dissolve in aqueous  $\text{NaHCO}_3$ ; 4-methylphenol ( $\text{p}K_a = 10.17$ ) will not.  
 (e) 4-Ethylphenol will dissolve in aqueous NaOH; ethyl phenyl ether will not.

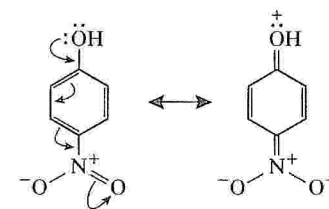
21.15 Both *o*- and *m*-toluidine are formed in the following way:



Both *m*- and *p*-toluidine are formed from another benzyne-type intermediate.

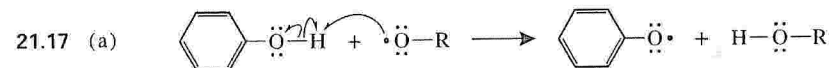


- 21.16 (a) 4-Fluorophenol because a fluorine substituent is more electron withdrawing than a methyl group.  
 (b) 4-Nitrophenol because a nitro group is more electron withdrawing than a methyl group.  
 (c) 4-Nitrophenol because the nitro group can exert an electron-withdrawing effect through a resonance effect.

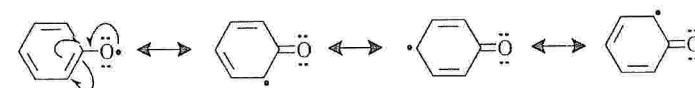


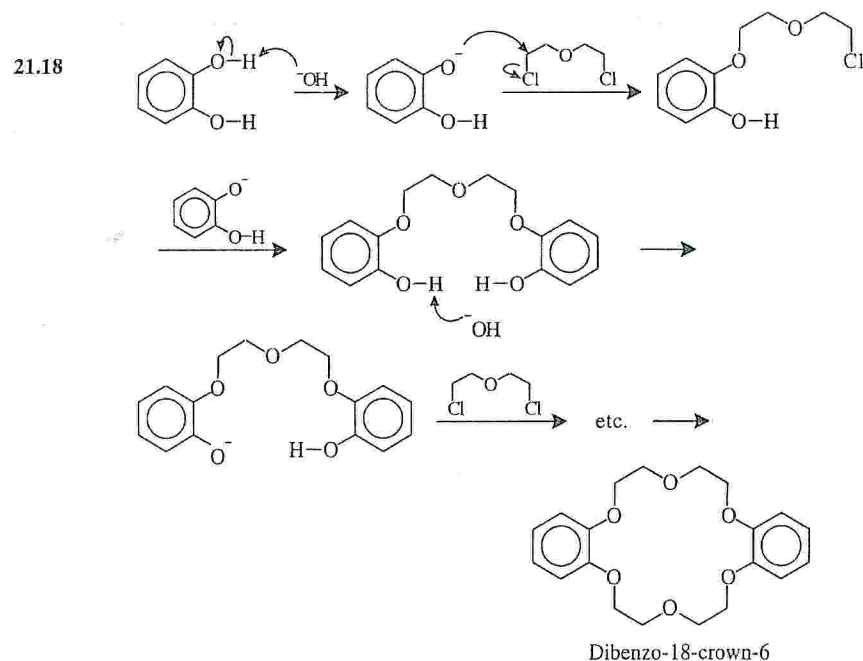
Whereas in 3-nitrophenol this resonance effect is not possible.

- (d) 4-Methylphenol because it is a phenol, not an alcohol.  
 (e) 4-Fluorophenol because fluorine is more electronegative than bromine.

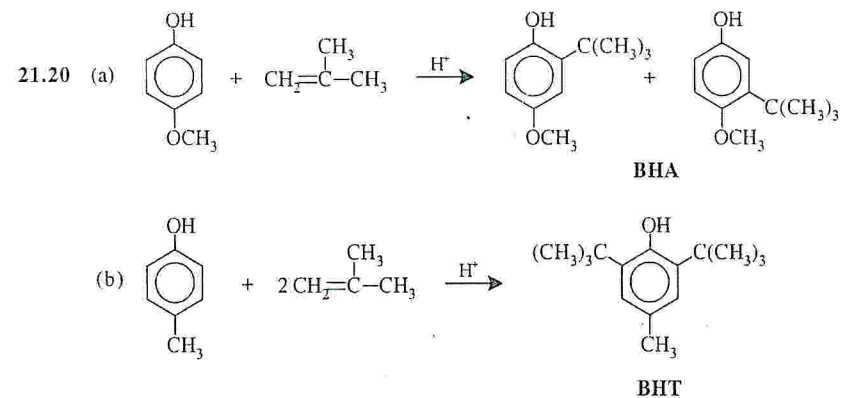
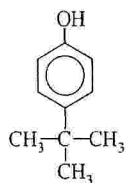


(b) Because the phenolic radical is highly stabilized by resonance (see the following structures), it is relatively unreactive.

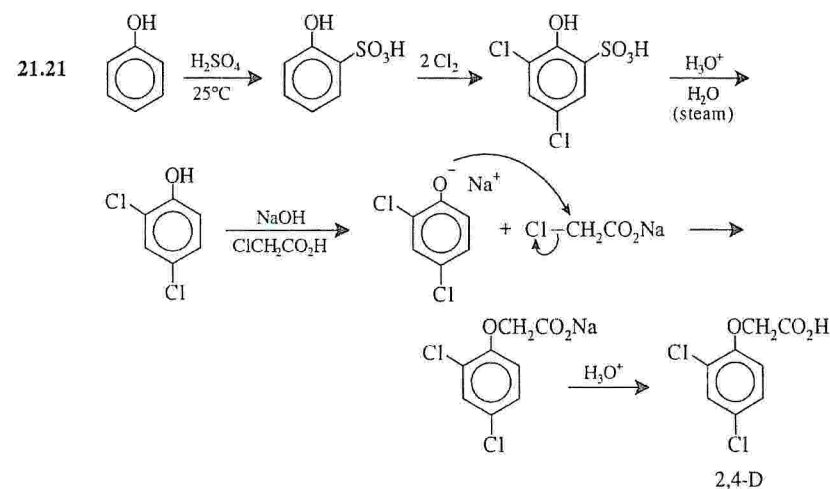




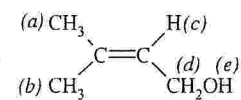
21.19 **X** is a phenol because it dissolves in aqueous NaOH but not in aqueous NaHCO<sub>3</sub>. It gives a dibromo derivative and must therefore be substituted in the ortho or para position. The broad IR peak at 3250 cm<sup>-1</sup> also suggests a phenol. The peak at 830 cm<sup>-1</sup> indicates para substitution. The <sup>1</sup>H NMR singlet at δ 1.3 (9H) suggests nine equivalent methyl hydrogen atoms, which must be a *tert*-butyl group. The structure of **X** is



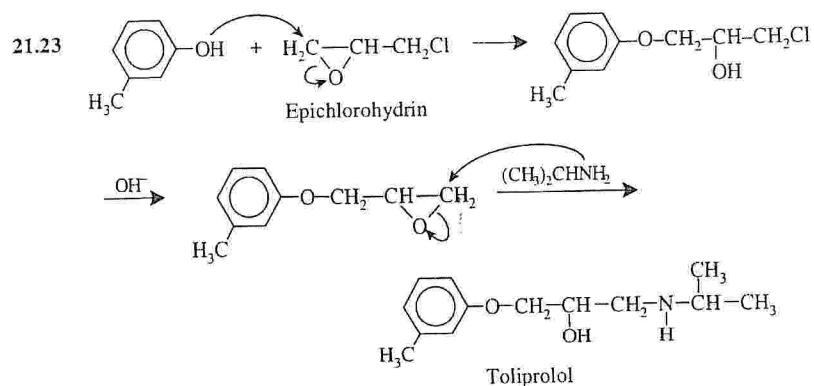
Notice that both reactions are Friedel-Crafts alkylations.



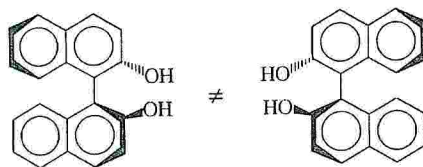
21.22 The broad IR peak at 3200–3600 cm<sup>-1</sup> suggests a hydroxyl group. The two <sup>1</sup>H NMR peaks at δ 1.67 and δ 1.74 are not a doublet because their separation is not equal to other splittings; therefore, these peaks are singlets. Reaction with Br<sub>2</sub>/CCl<sub>4</sub> suggests an alkene. If we put these bits of information together, we conclude that **Z** is 3-methyl-2-buten-1-ol.



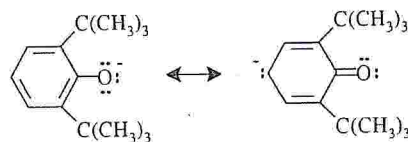
(a) and (b) singlets δ 1.67 and δ 1.74  
 (c) multiplet δ 5.40  
 (d) doublet δ 4.10  
 (e) singlet δ 2.3



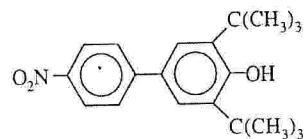
**21.24** The proximity of the two -OH groups results in the two naphthalene nuclei being non-coplanar. As a result, the two enantiomeric forms are nonequivalent and can be separated by a resolution technique.



**21.25** One can draw a resonance structure for the 2,6-di-*tert*-butylphenoxide ion which shows the carbon para to the oxygen as a nucleophilic center; that is, the species is an ambident nucleophile.



Given the steric hindrance about the oxygen, the nucleophilic character of the para carbon is dominant and an  $S_NAr$  reaction occurs at that position to produce this biphenyl derivative:

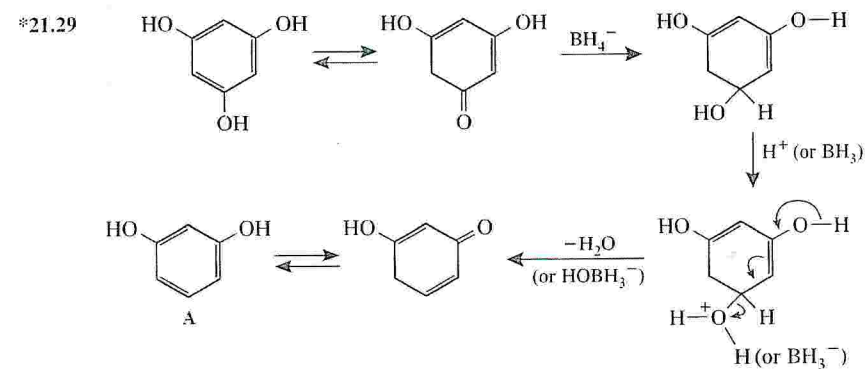
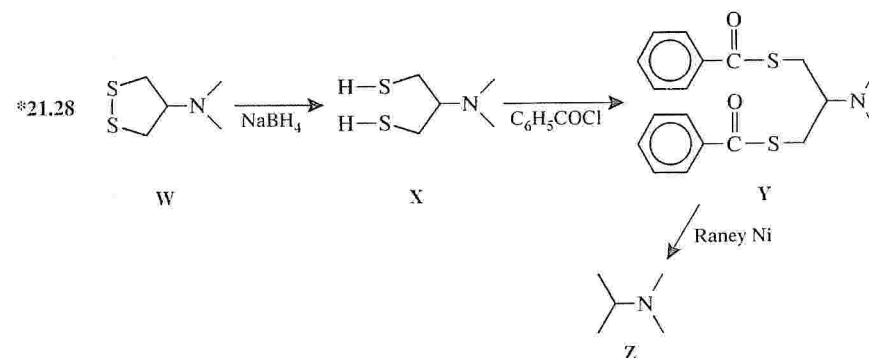


**21.26** The phenoxide ion has nucleophilic character both at the oxygen and at the carbon para to it; it is ambident.



The benzyne produced by the elimination phase of the reaction can undergo addition then by attack by either nucleophilic center, reaction at oxygen producing **1** and reaction at carbon producing **2**.

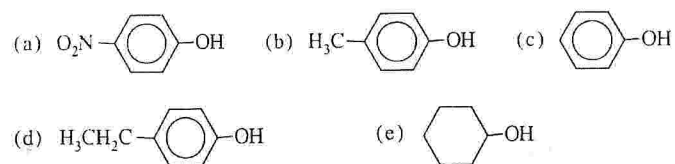
**21.27**  $\text{H}^-$  is expected to be a very poor leaving group because of the strong basicity of the hydride ion. In this case the reaction is favored not only by the activating nitro groups but also by the oxidant ferricyanide ion, which converts  $\text{H}^-$ , as it forms, to  $\text{H}_2$ .



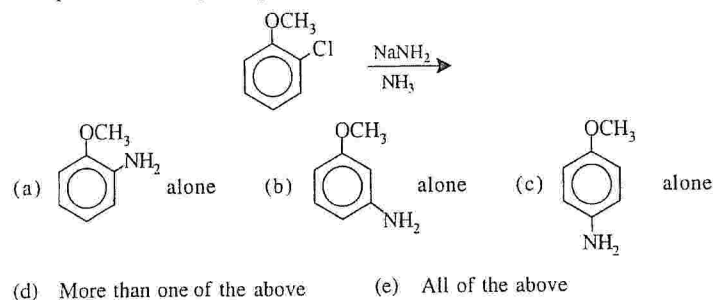


## QUIZ

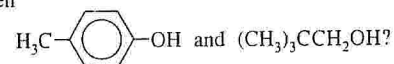
21.1 Which of the following would be the strongest acid?



21.2 What products would you expect from the following reaction?

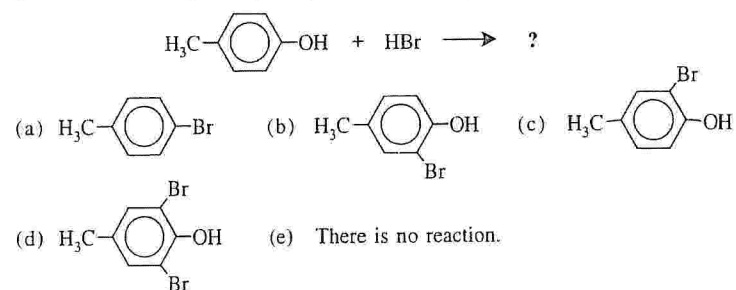


21.3 Which of the reagents listed here would serve as the basis for a simple chemical test to distinguish between

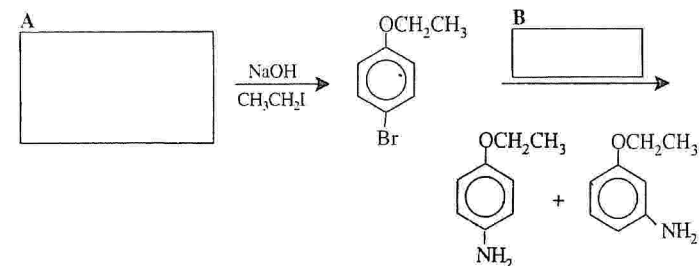


- (a)  $\text{Ag}(\text{NH}_3)_2\text{OH}$  (d) Cold concd.  $\text{H}_2\text{SO}_4$   
 (b)  $\text{NaOH}/\text{H}_2\text{O}$  (e) None of the above  
 (c) Dilute  $\text{HCl}$

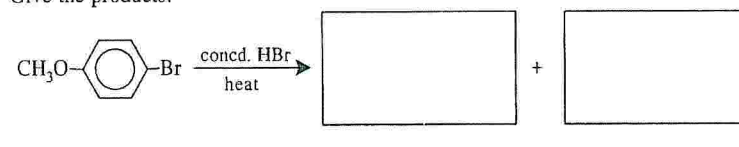
21.4 Indicate the correct product, if any, of the following reaction.



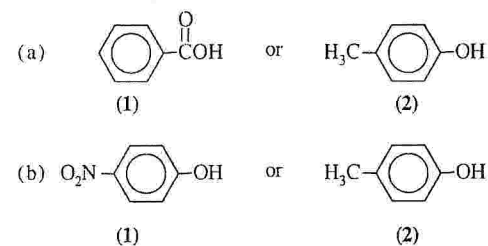
21.5 Complete the following synthesis:



21.6 Give the products:



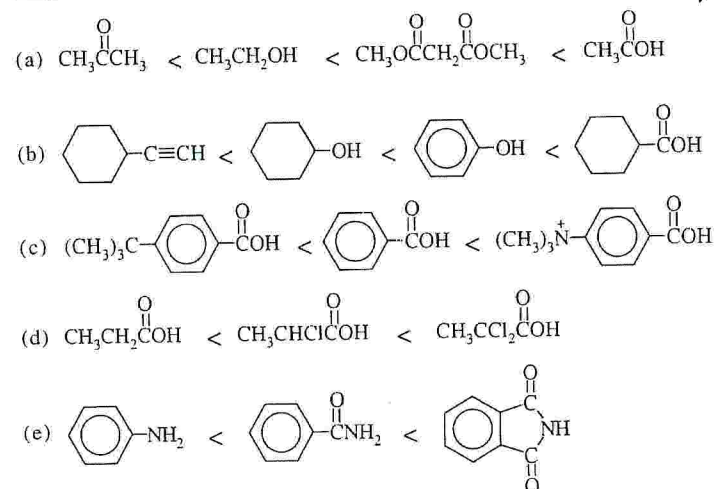
21.7 Select the stronger acid.



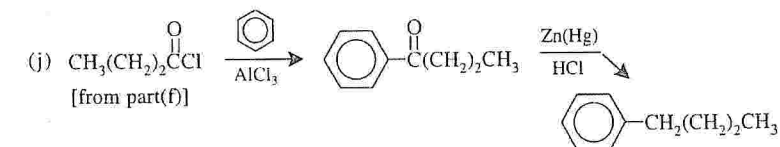
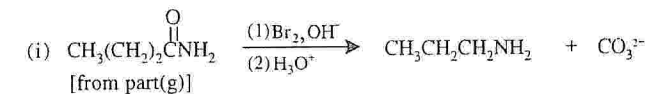
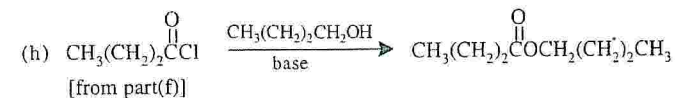
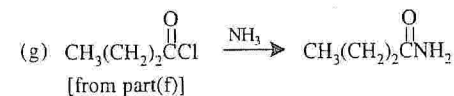
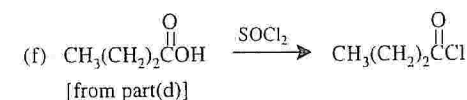
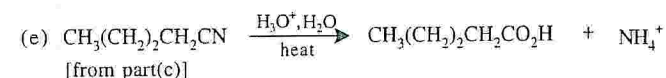
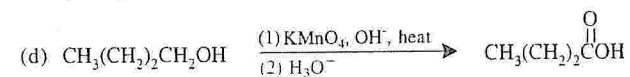
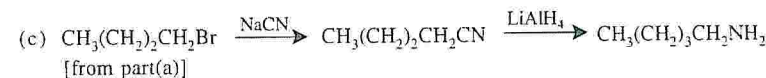
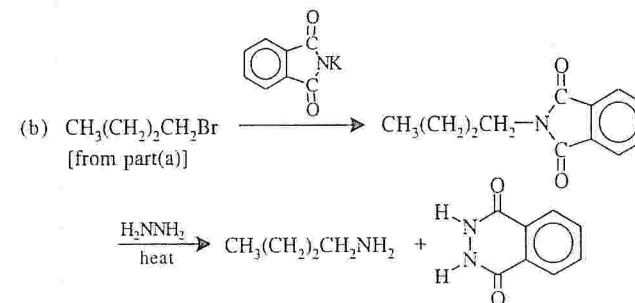
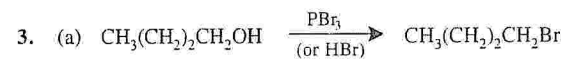
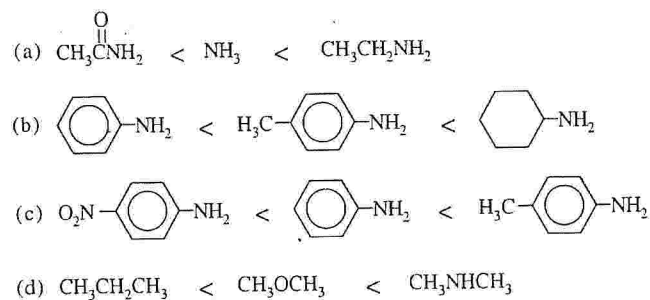
# ANSWERS TO SECOND REVIEW PROBLEM SET

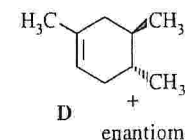
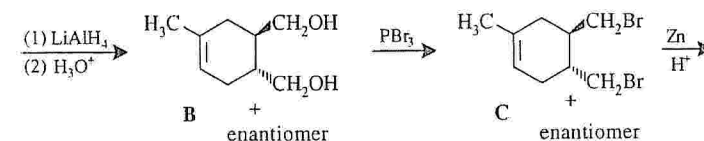
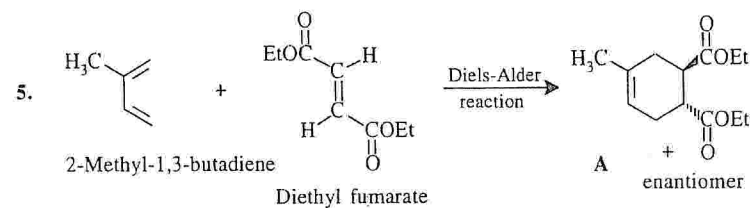
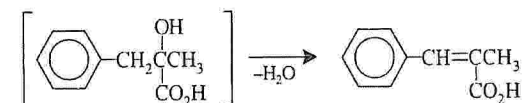
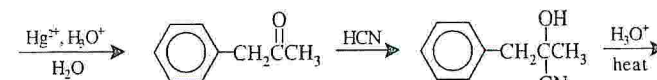
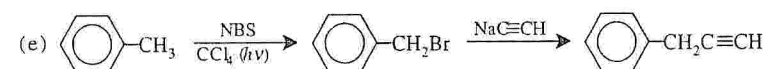
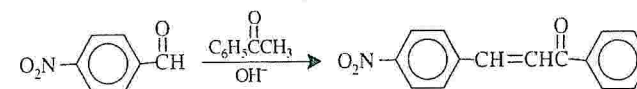
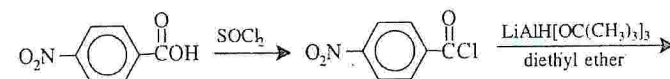
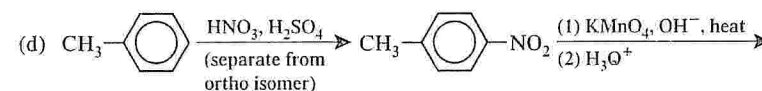
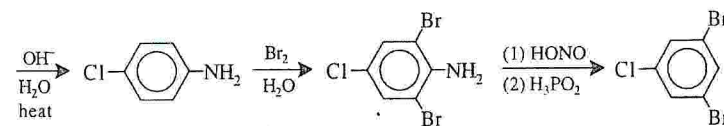
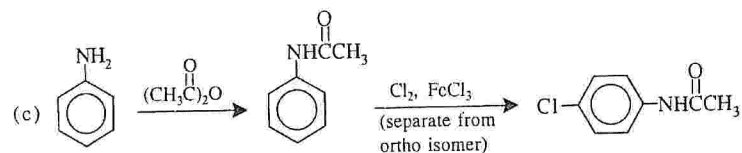
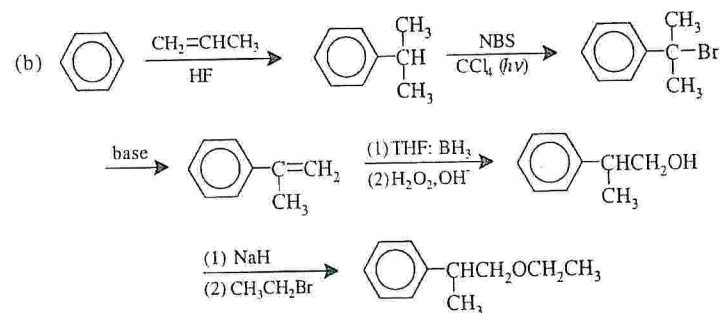
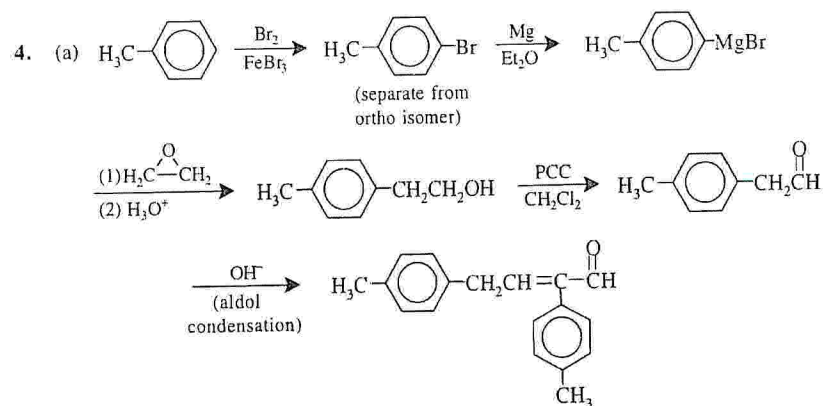
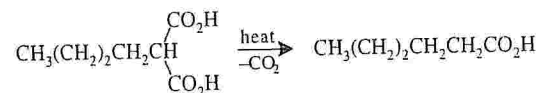
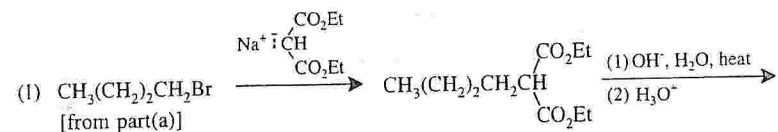
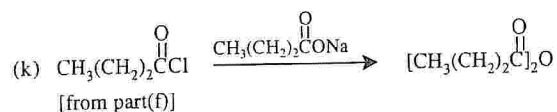
The problems review concepts from Chapters 13-21.

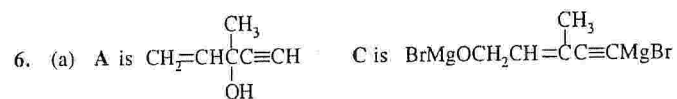
## 1. Increasing acidity



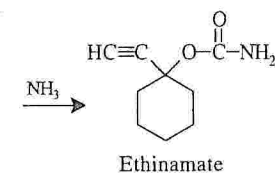
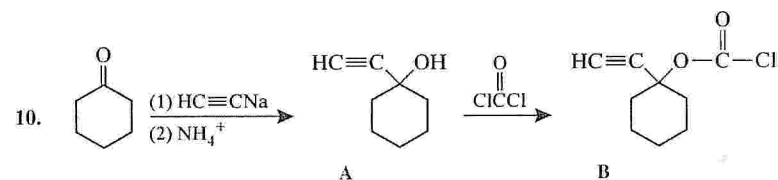
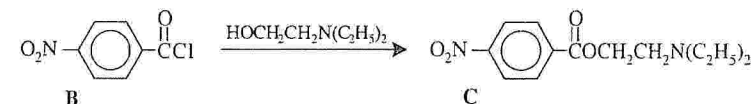
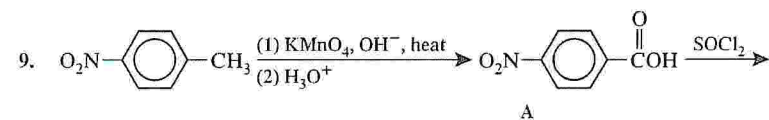
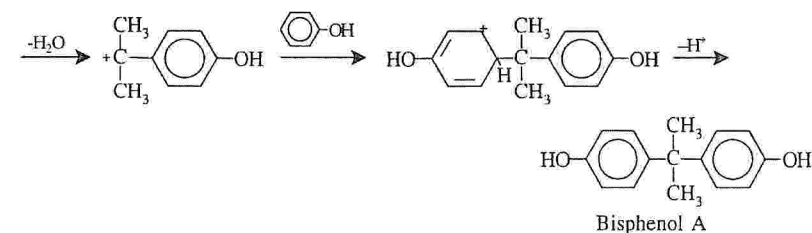
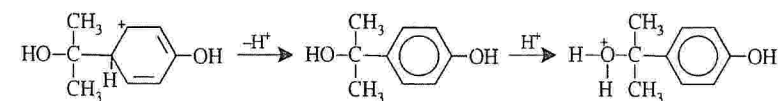
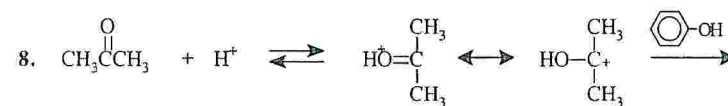
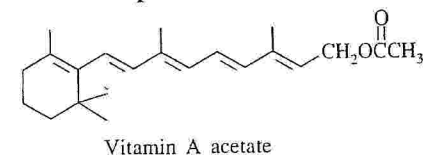
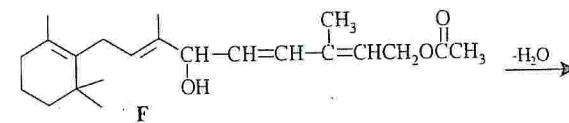
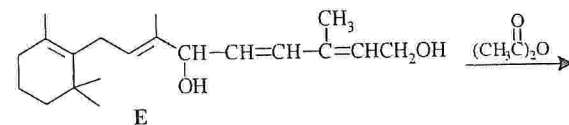
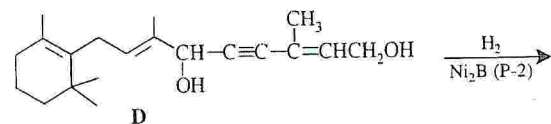
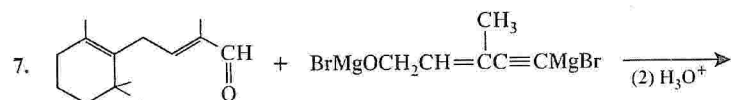
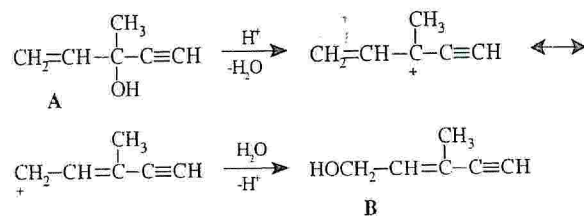
## 2. Increasing basicity



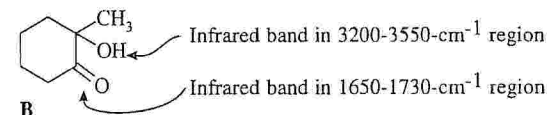
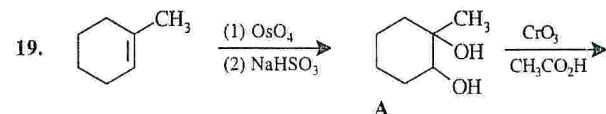
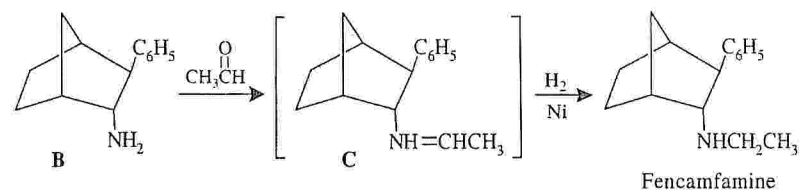
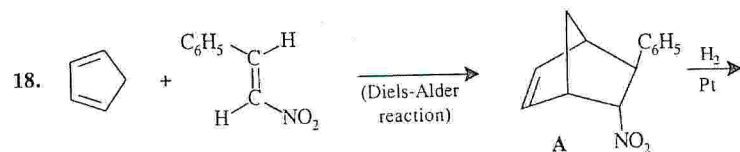
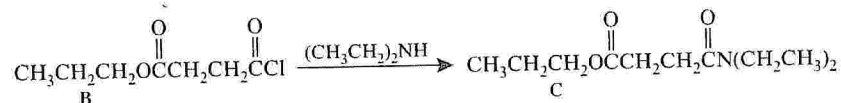
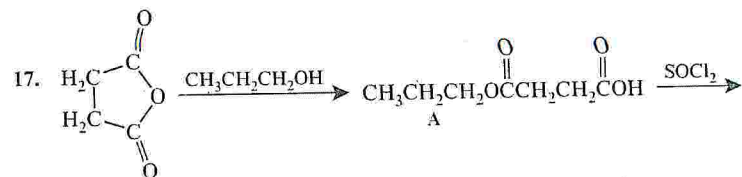
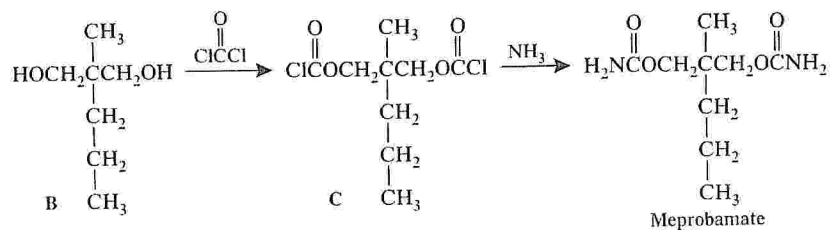
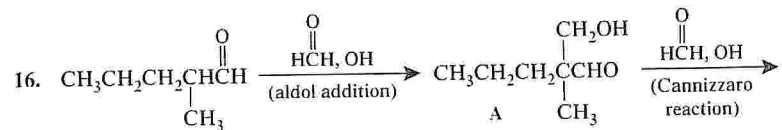
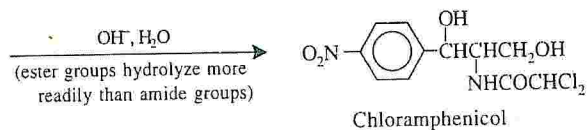
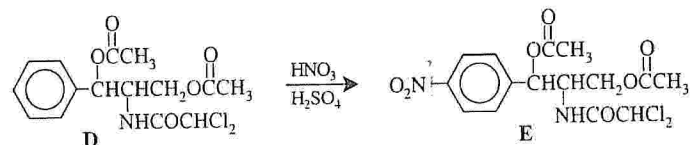
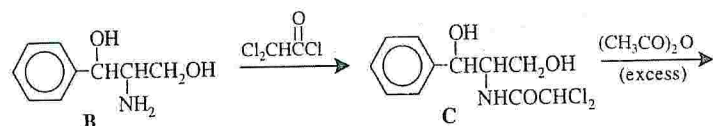




(b) A is an allylic alcohol and thus forms a carbocation readily. B is a conjugated enyne and is therefore more stable than A.

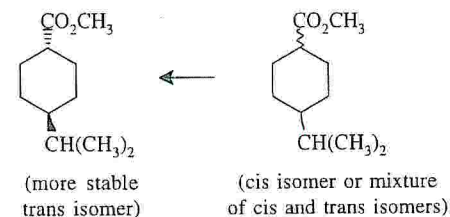




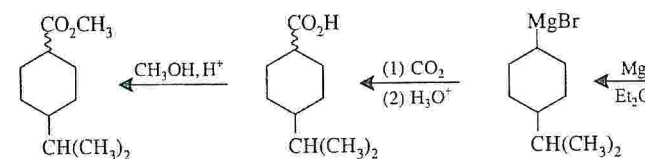


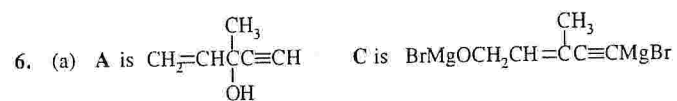
Notice that the second step involves the oxidation of a secondary alcohol in the presence of a tertiary alcohol. This selectivity is possible because tertiary alcohols do not undergo oxidation readily (Section 11.8)

20. Working backward, we notice that methyl *trans*-4-isopropylcyclohexanecarboxylate has both large groups equatorial and is, therefore, more stable than the corresponding *cis* isomer. This stability of the *trans* isomer means that, if we were to synthesize the *cis* isomer or a mixture of both the *cis* and *trans* isomers, we could obtain the desired *trans* isomer by a base-catalyzed isomerization (epimerization):

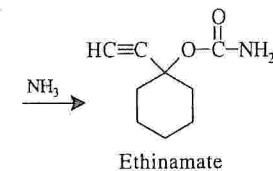
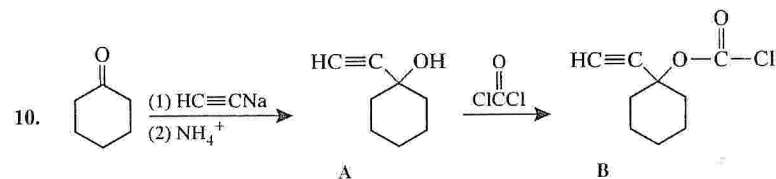
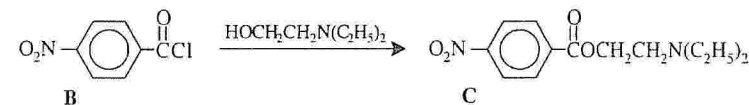
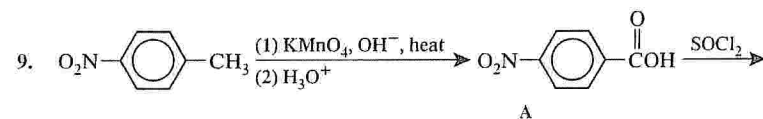
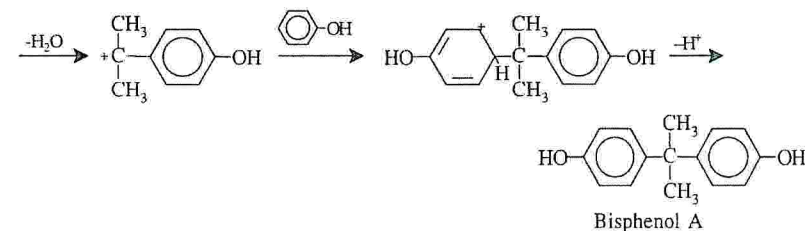
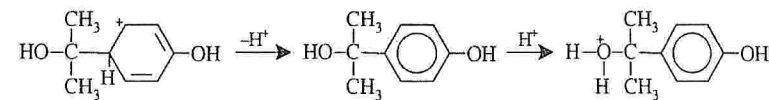
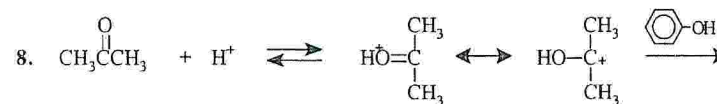
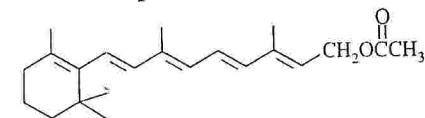
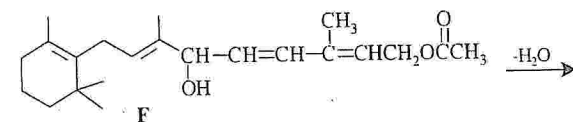
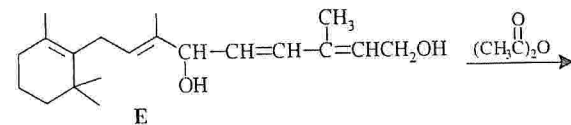
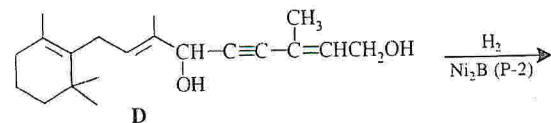
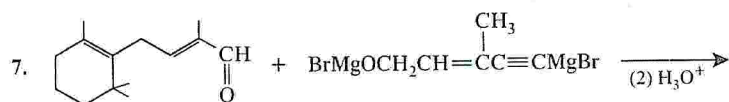
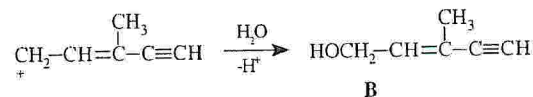
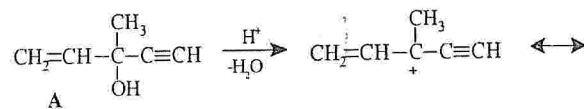


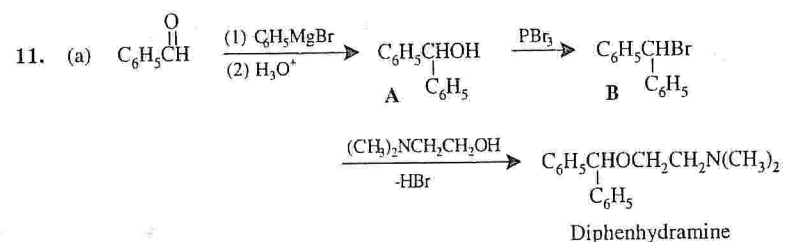
We could synthesize a mixture of the desired isomers from phenol in the following way:



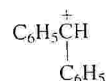


(b) A is an allylic alcohol and thus forms a carbocation readily. B is a conjugated enyne and is therefore more stable than A.

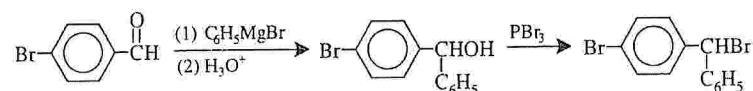




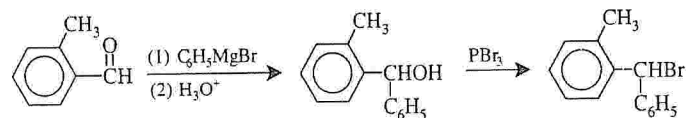
(b) The last step probably takes place by an  $\text{S}_{\text{N}}1$  mechanism. Diphenylmethyl bromide, B, ionizes readily because it forms the resonance-stabilized benzylic carbocation,



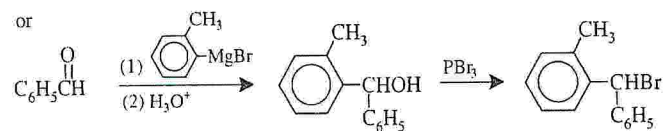
12. (a) For this synthesis we need to prepare the benzylic halide,  $\text{Br}-\text{C}_6\text{H}_4-\text{CHBr}-\text{C}_6\text{H}_5$ , and then allow it to react with  $(\text{CH}_3)_2\text{NCH}_2\text{CH}_2\text{OH}$  as in Problem 11. This benzylic halide can be made as follows:



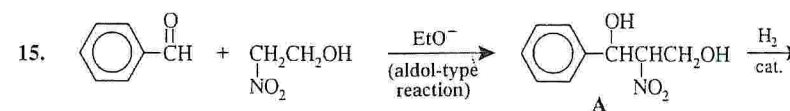
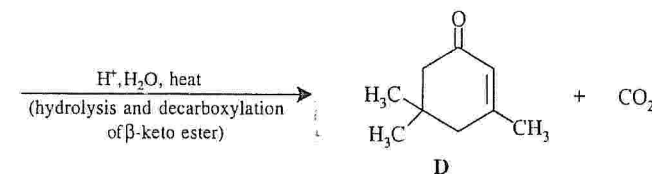
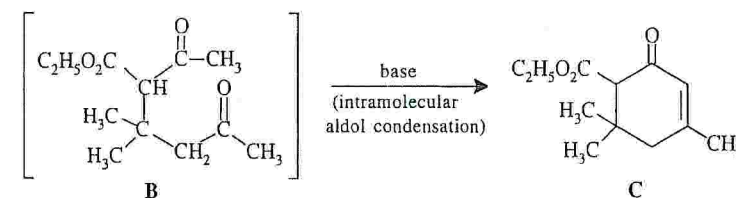
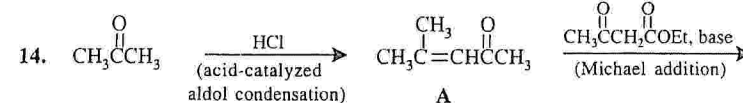
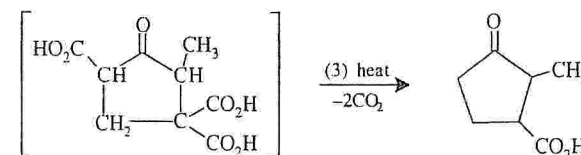
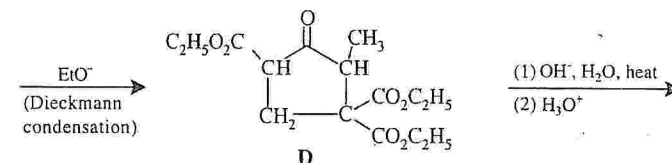
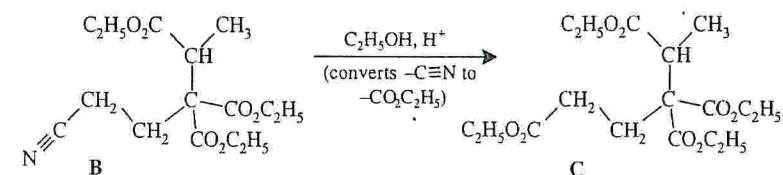
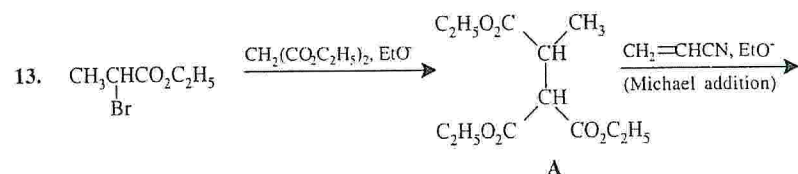
(b) For this synthesis we can prepare the requisite benzylic halide in two ways:

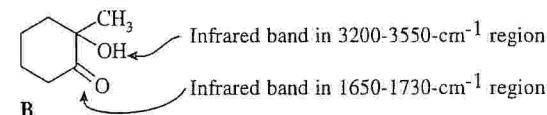
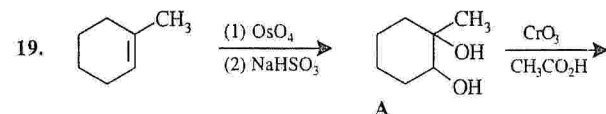
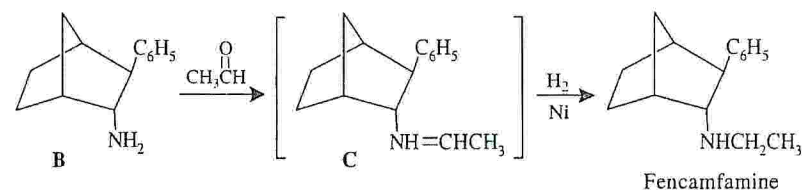
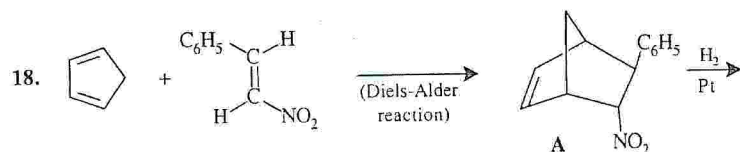
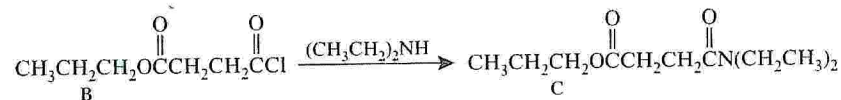
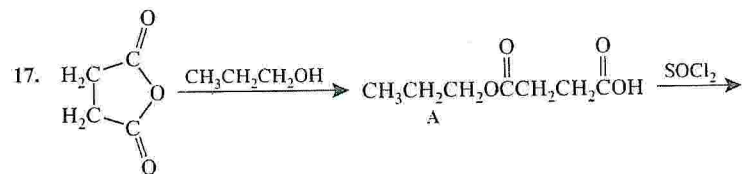
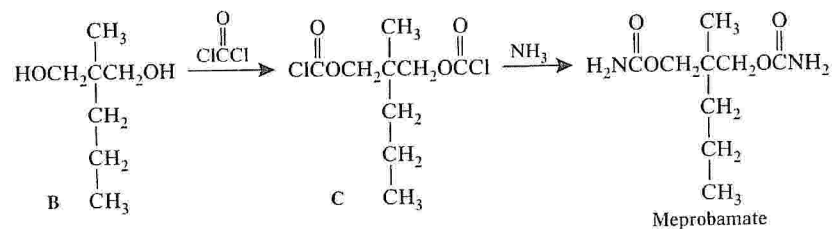
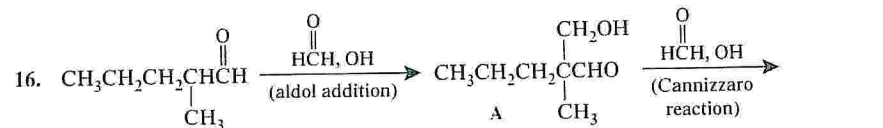
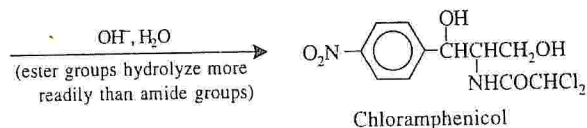
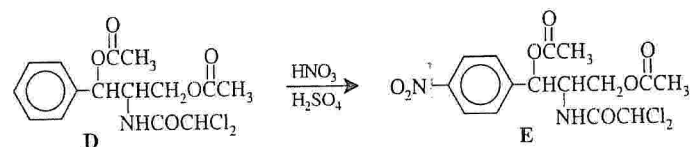
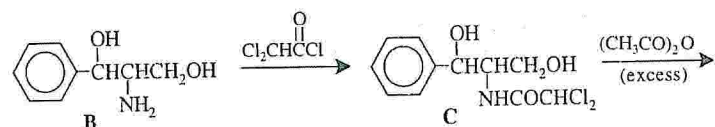


or



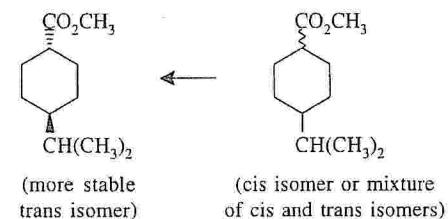
We shall then allow the benzylic halide to react with  $(\text{CH}_3)_2\text{NCH}_2\text{CH}_2\text{OH}$  as in Problem 11.



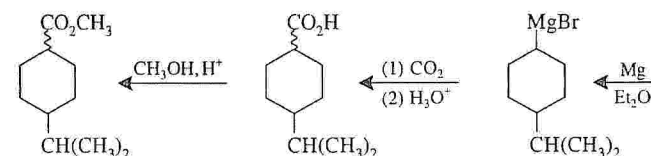


Notice that the second step involves the oxidation of a secondary alcohol in the presence of a tertiary alcohol. This selectivity is possible because tertiary alcohols do not undergo oxidation readily (Section 11.8)

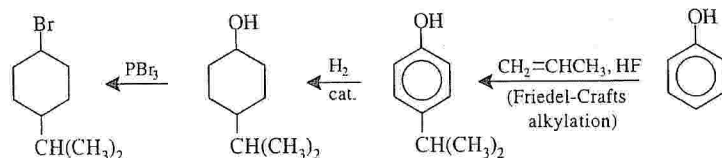
20. Working backward, we notice that methyl *trans*-4-isopropylcyclohexanecarboxylate has both large groups equatorial and is, therefore, more stable than the corresponding *cis* isomer. This stability of the *trans* isomer means that, if we were to synthesize the *cis* isomer or a mixture of both the *cis* and *trans* isomers, we could obtain the desired *trans* isomer by a base-catalyzed isomerization (epimerization):



We could synthesize a mixture of the desired isomers from phenol in the following way:





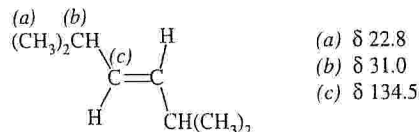


21. That **Y** gives a green opaque solution when treated with  $\text{CrO}_3$  in aqueous  $\text{H}_2\text{SO}_4$  indicates that **Y** is a primary or secondary alcohol. That **Y** gives a negative iodoform test indicates that **Y** does not contain the grouping  $-\text{CH}(\text{CH}_3)_2$ . The  $^{13}\text{C}$  spectrum of **Y** contains

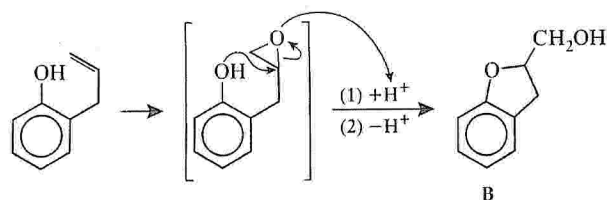
|                   |                   |
|-------------------|-------------------|
| (a) $\delta$ 11.1 | (a) $\delta$ 11.1 |
| (b) $\delta$ 23.0 | (b) $\delta$ 23.0 |
| (c) $\delta$ 43.6 | (c) $\delta$ 43.6 |
| (d) $\delta$ 64.6 | (d) $\delta$ 64.6 |

only four signals indicating that some of the carbons in **Y** are equivalent. The information from DEPT spectra helps us conclude that **Y** is 2-ethyl-1-butanol.

22. That **Z** decolorizes bromine in  $\text{CCl}_4$  indicates that **Z** is an alkene. We are told that **Z** is the more stable isomer of a pair of stereoisomers. This fact suggests that **Z** is a *trans* alkene. That the  $^{13}\text{C}$  spectrum contains only three signals, even though **Z** contains eight carbon atoms, indicates that **Z** is highly symmetric. The information from DEPT spectra indicates that the upfield signals of the alkyl groups arise from equivalent isopropyl groups. We conclude, therefore, that **Z** is *trans*-2,5-dimethyl-3-hexene.



23.



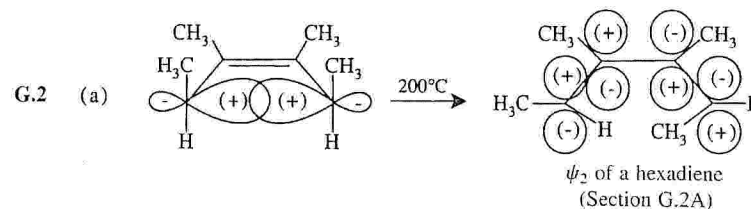
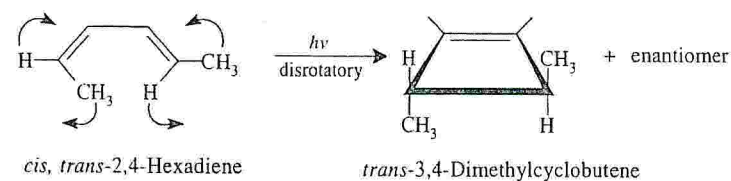
## G

## SPECIAL TOPIC

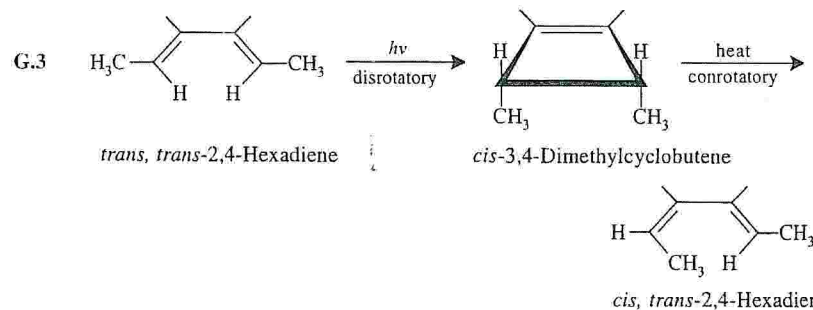
## Electrocyclic and Cycloaddition Reactions

## SOLUTIONS TO PROBLEMS

- G.1 According to the Woodward-Hoffmann rule for electrocyclic reactions of  $4n$   $\pi$ -electron systems (Section G.2A), the photochemical cyclization of *cis, trans*-2,4-hexadiene should proceed with *disrotatory motion*. Thus, it should yield *trans*-3,4-dimethylcyclobutene:

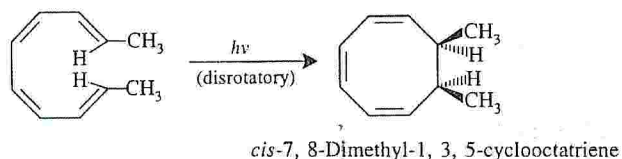


- (b) This is a thermal electrocyclic reaction of a  $4n$   $\pi$ -electron system; it should, and does, proceed with conrotatory motion.

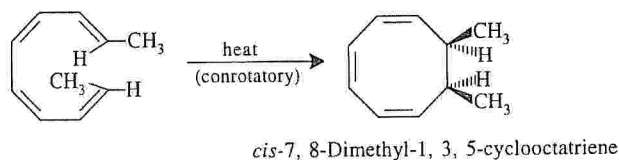


Here we find that two consecutive electrocyclic reactions (the first photochemical, the second thermal), provide a stereospecific synthesis of *cis, trans*-2,4-hexadiene from *trans, trans*-2,4-hexadiene.

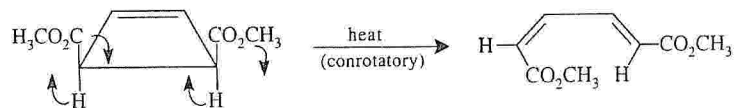
- G.4 (a) This is a photochemical electrocyclic reaction of an eight  $\pi$ -electron system—a  $4n$   $\pi$ -electron system where  $n = 2$ . It should, therefore, proceed with disrotatory motion.



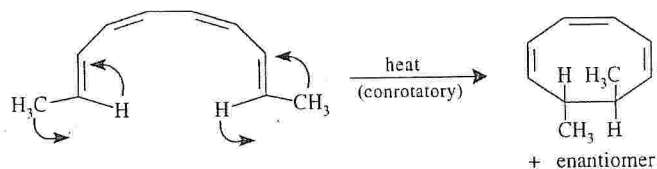
- (b) This is a thermal electrocyclic reaction of the eight  $\pi$ -electron system. It should proceed with conrotatory motion.



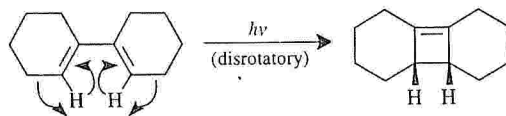
- G.5 (a) This is conrotatory motion, and since this is a  $4n$   $\pi$ -electron system (where  $n = 1$ ) it should occur under the influence of heat.



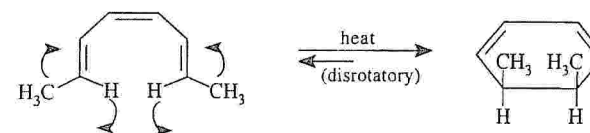
- (b) This is conrotatory motion, and since this is also a  $4n$   $\pi$ -electron system (where  $n = 2$ ) it should occur under the influence of heat.



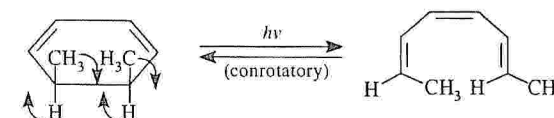
- (c) This is disrotatory motion. This, too, is a  $4n$   $\pi$ -electron system (where  $n = 1$ ); thus it should occur under the influence of light.



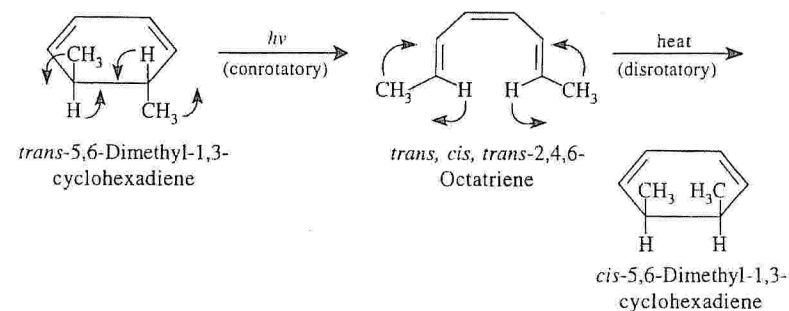
- G.6 (a) This is a  $(4n + 2)$   $\pi$ -electron system (where  $n = 1$ ); a thermal reaction should take place with disrotatory motion:



- (b) This is also a  $(4n + 2)$   $\pi$ -electron system; a photochemical reaction should take place with conrotatory motion.

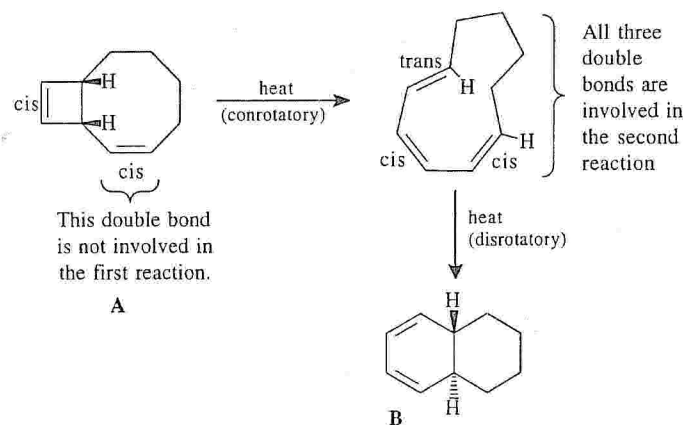


- G.7 Here we need a conrotatory ring opening of *trans*-5,6-dimethyl-1,3-cyclohexadiene (to produce *trans,cis,trans*-2,4,6-octatriene); then we need a disrotatory cyclization to produce *cis*-5,6-dimethyl-1,3-cyclohexadiene.

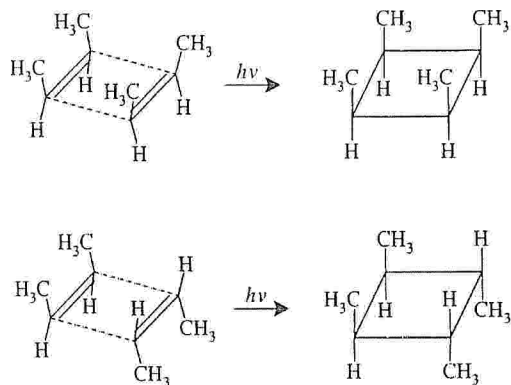


Since both reactions involve  $(4n + 2)$   $\pi$ -electron systems, we apply light to accomplish the first step and heat to accomplish the second. It would also be possible to use heat to produce *trans,cis,cis*-2,4,6-octatriene and then use light to produce the desired product.

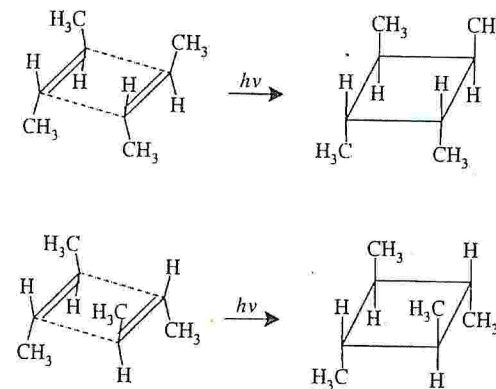
- G.8 The first electrocyclic reaction is a thermal, conrotatory ring opening of a  $4n$   $\pi$ -electron system. The second electrocyclic reaction is a thermal, disrotatory ring closure of a  $(4n + 2)$   $\pi$ -electron system.



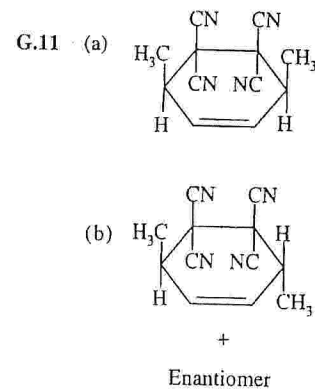
- G.9 (a) There are two possible products that can result from a concerted cycloaddition. They are formed when *cis*-2-butene molecules come together in the following ways:



- (b) There are two possible products that can be obtained from *trans*-2-butene as well.



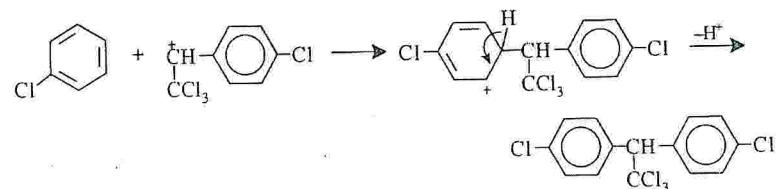
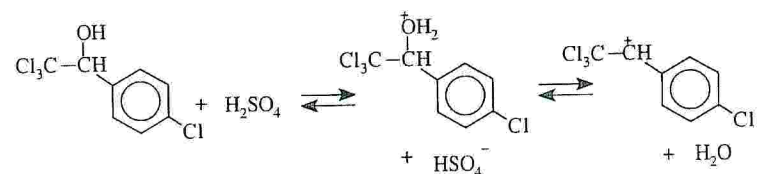
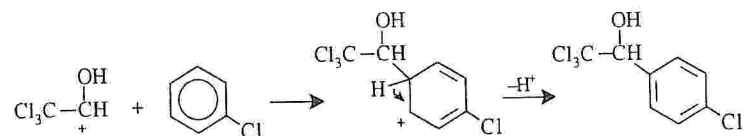
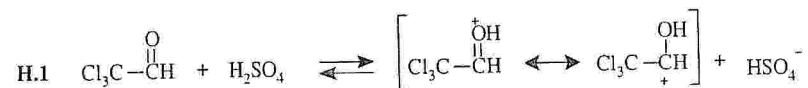
- G.10 This is an intramolecular  $[2 + 2]$  cycloaddition.



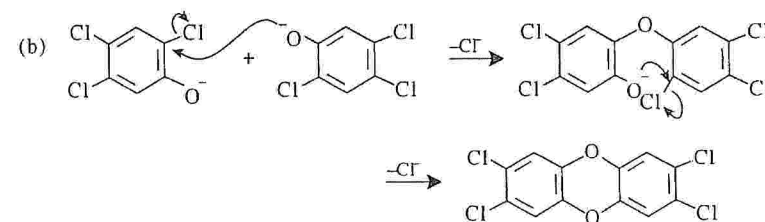
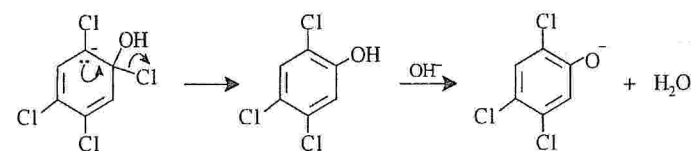
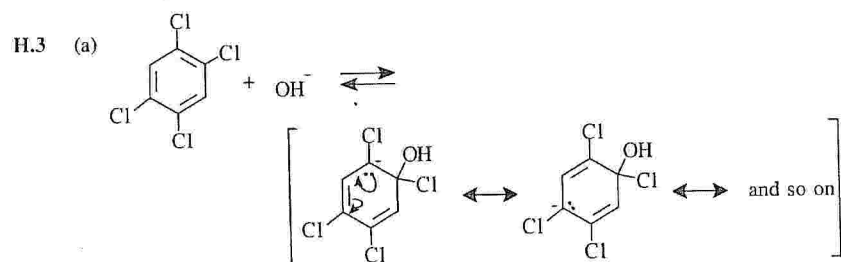
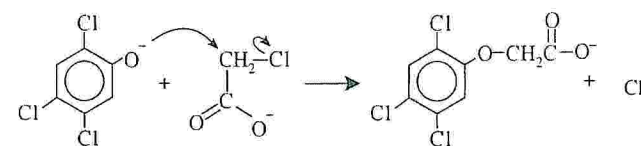
## SPECIAL TOPIC

Organic Halides and  
Organometallic Compounds in the Environment

## SOLUTIONS TO PROBLEMS



H.2 An elimination reaction.

H.4 An  $\text{S}_{\text{N}}2$  reaction:

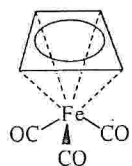


# SPECIAL TOPIC

## Transition Metal Organometallic Compounds

### SOLUTIONS TO PROBLEMS

I.1

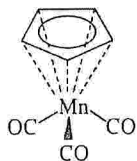


Cyclobutadiene iron tricarbonyl

Total number of valence electrons (both  $s$  and  $d$  electrons) of elemental iron — oxidation state of the metal in the complex

$$d^n = 8 - 0 = 8$$

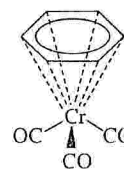
$$\begin{aligned} \text{Total number of valence electrons of iron in the complex} &= d^n + \text{electrons donated by ligands} \\ &= 8 + 3(\text{CO}) + \text{cyclobutadiene} \\ &= 8 + 3(2) + 4 = 18 \end{aligned}$$



Cyclopentadienylmanganese tricarbonyl

$$d^n = 7 - 1 = 6$$

$$\begin{aligned} \text{Total number of valence electrons of Mn in complex} &= 6 + 3(\text{CO}) + \text{Cp} \\ &= 6 + 3(2) + 6 = 18 \end{aligned}$$

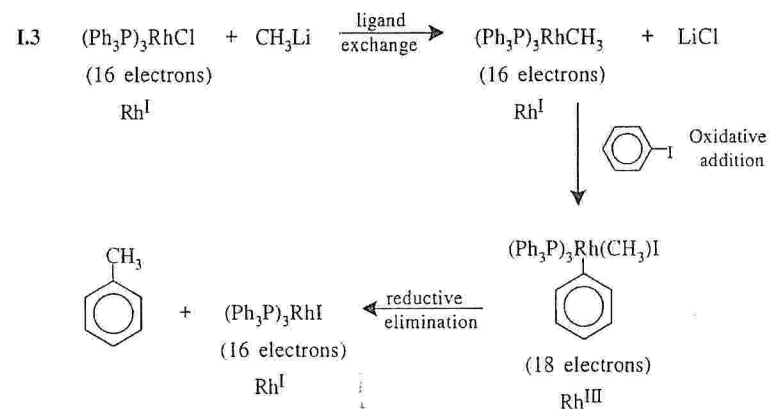
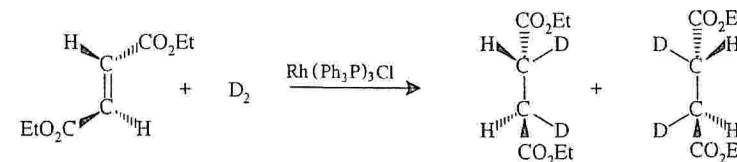


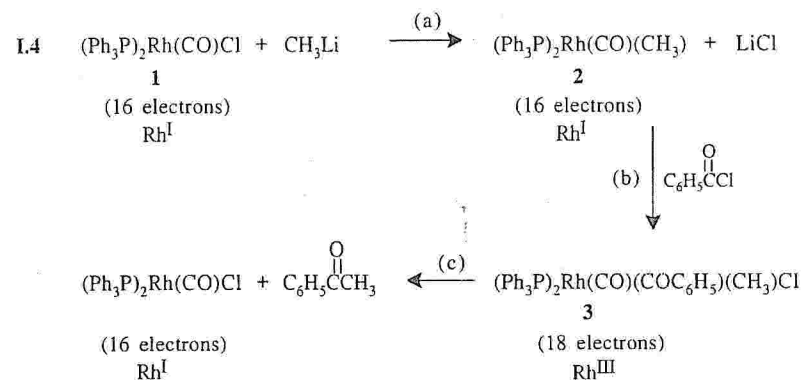
Benzene chromium tricarbonyl

$$d^n = 6 - 0 = 6$$

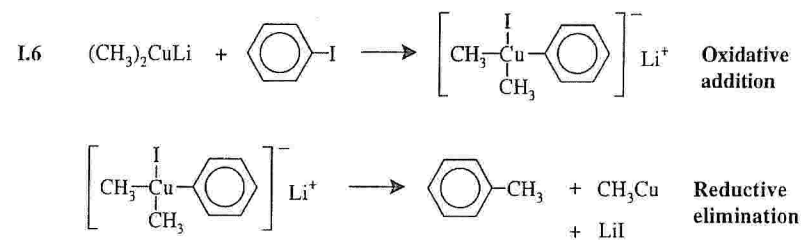
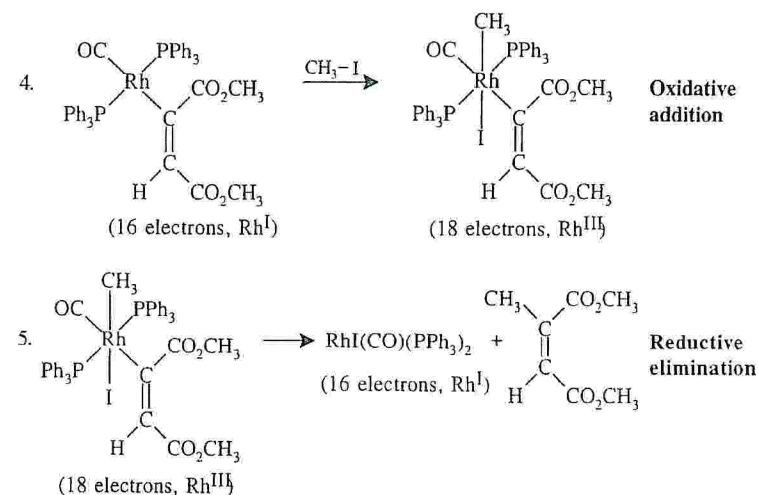
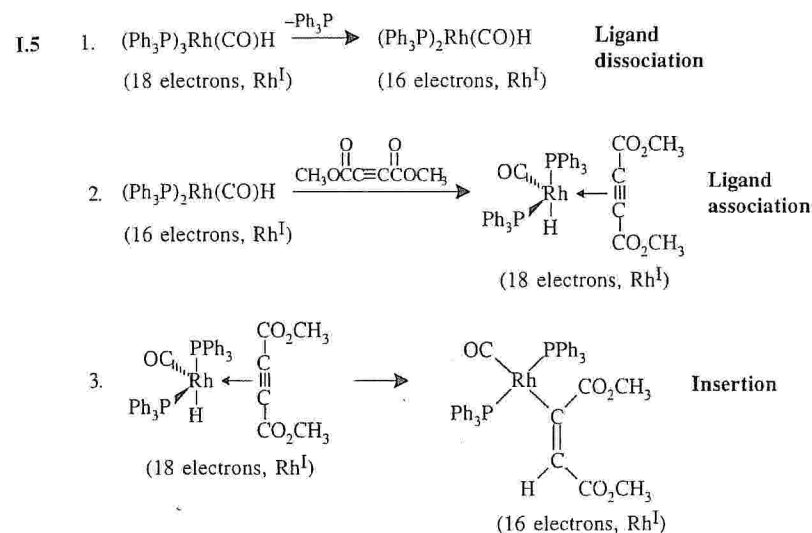
$$\begin{aligned} \text{Total number of valence electrons of Cr in complex} &= 6 + 3(\text{CO}) + \text{benzene} \\ &= 6 + 3(2) + 6 = 18 \end{aligned}$$

I.2 A syn addition of  $\text{D}_2$  to the *trans* alkene would produce the following racemic form.



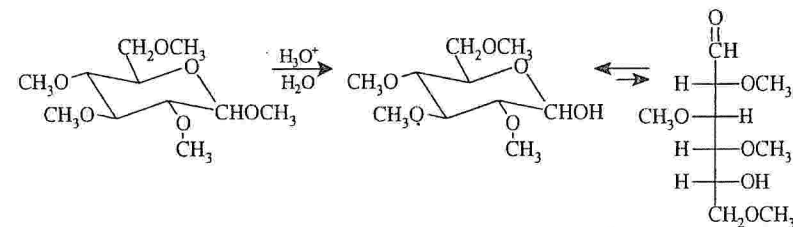
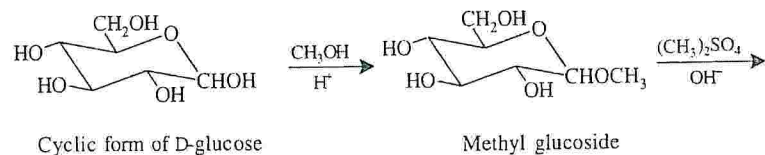
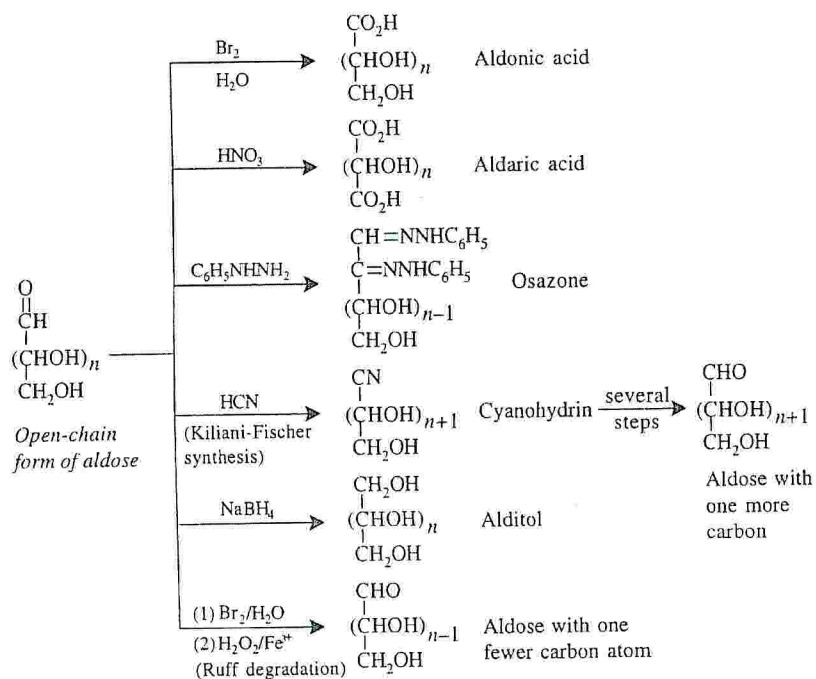


- (a) Is a ligand exchange  
 (b) Is an oxidative addition  
 (c) Is a reductive elimination

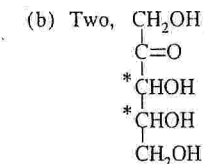
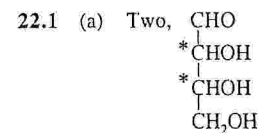


# 22 CARBOHYDRATES

## SUMMARY OF SOME REACTIONS OF MONOSACCHARIDES

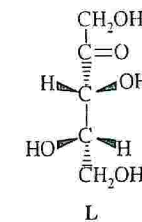
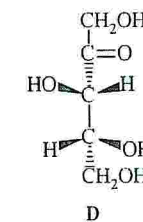
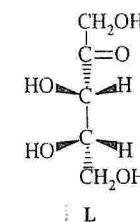
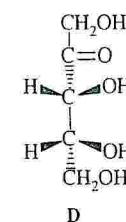
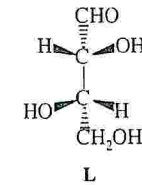
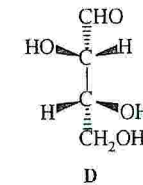
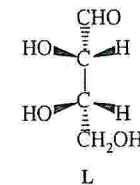
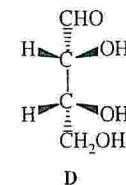


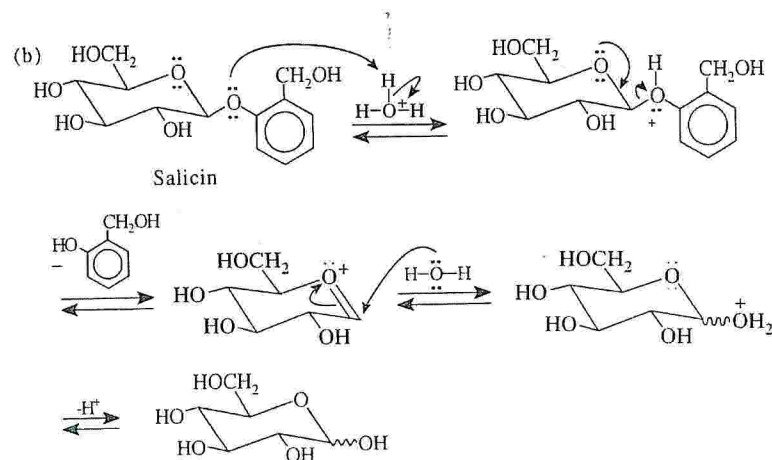
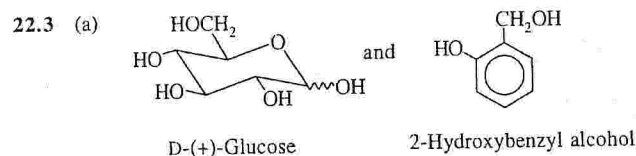
## SOLUTIONS TO PROBLEMS



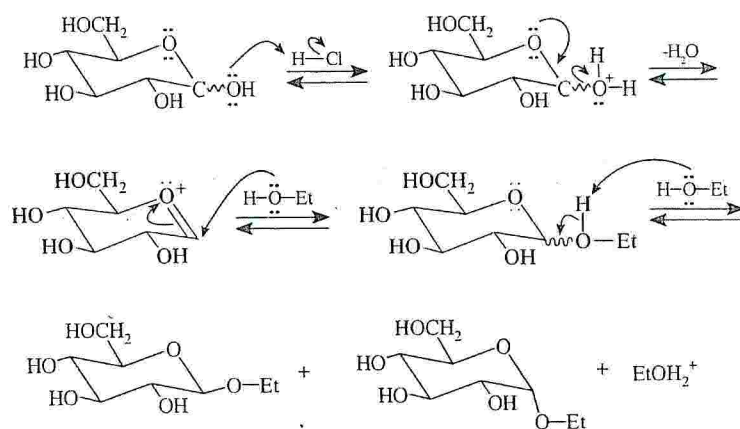
(c) There would be four stereoisomers (two sets of enantiomers) with each general structure:  $2^2 = 4$ .

22.2





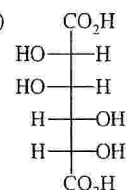
22.4 Dissolve D-glucose in ethanol and then bubble in gaseous HCl.



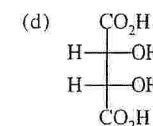
22.5 Since glycosides are acetals, they undergo hydrolysis in aqueous acid to form cyclic hemiacetals that then undergo mutarotation.

22.6  $\alpha$ -D-Glucopyranose will give a positive test with Benedict's or Tollens' solution because it is a cyclic hemiacetal. Methyl  $\alpha$ -D-glucopyranoside, because it is a cyclic acetal, will not.

22.7 (a) Yes

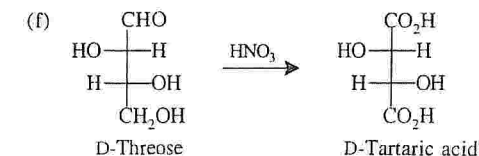
(b) 

(c) Yes



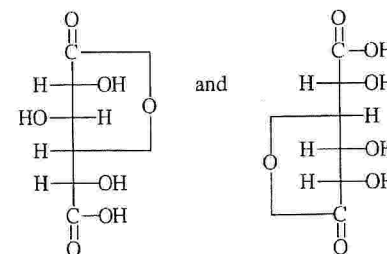
D-Mannaric acid

(e) No

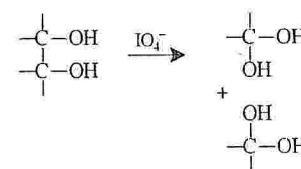


(g) The aldaric acid obtained from D-erythrose is *meso*-tartaric acid; the aldaric acid obtained from D-threose is D-tartaric acid.

22.8

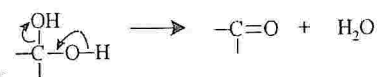
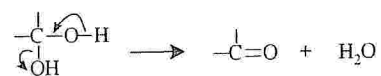


22.9 One way of predicting the products from a periodate oxidation is to place an -OH group on each carbon atom at the point where C-C bond cleavage has occurred:

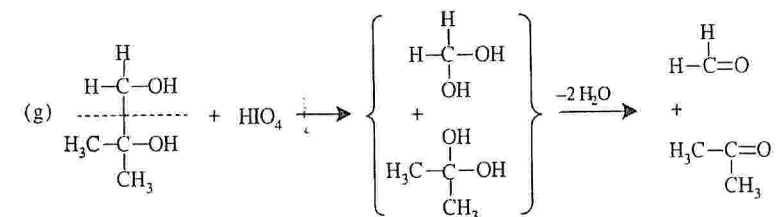
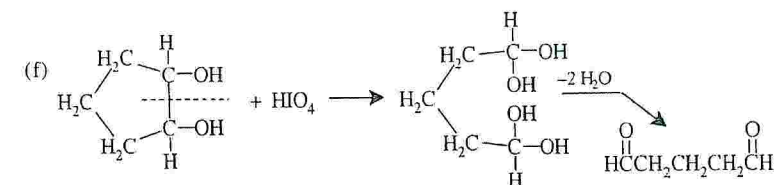
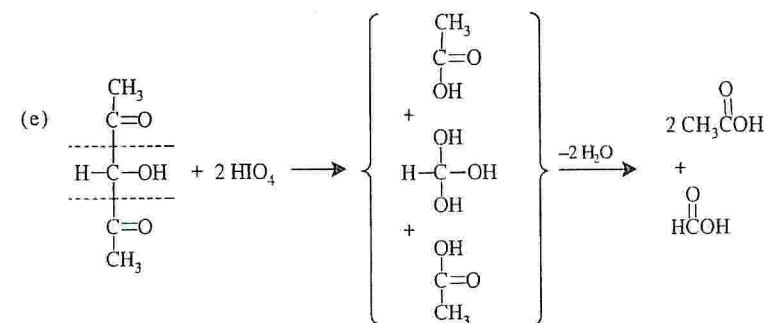
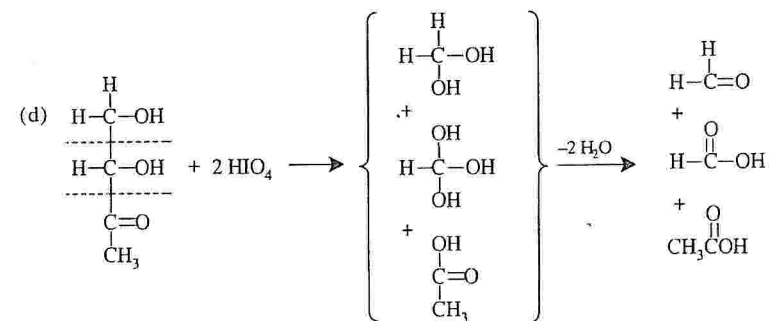
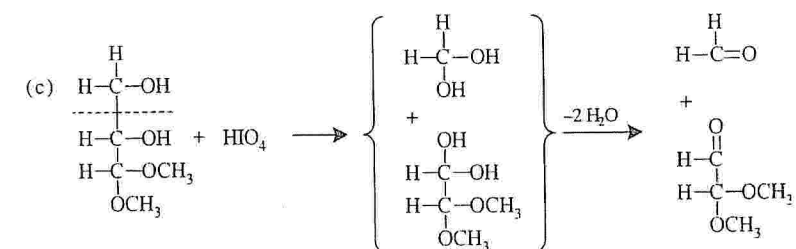
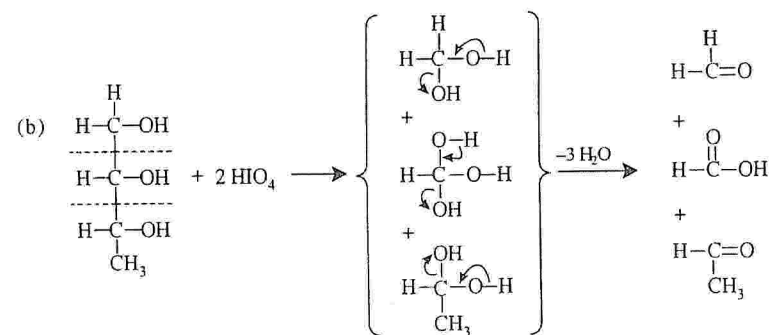
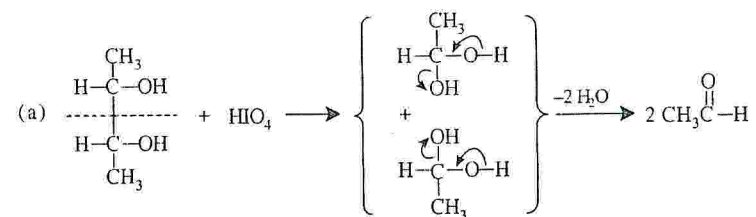


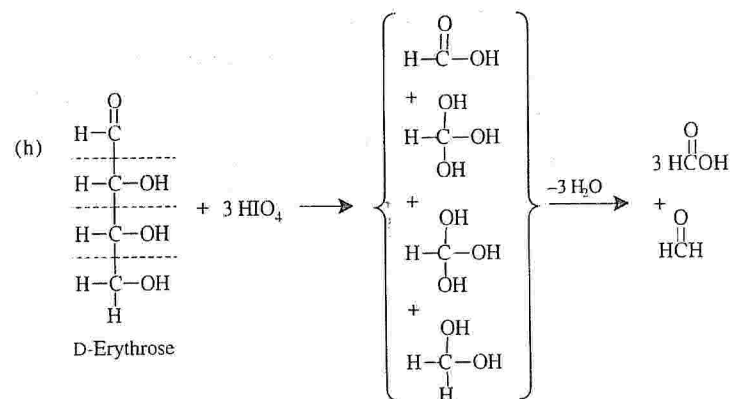


Then if we recall (Section 16.7A) that *gem*-diols are usually unstable and lose water to produce carbonyl compounds, we get the following results:

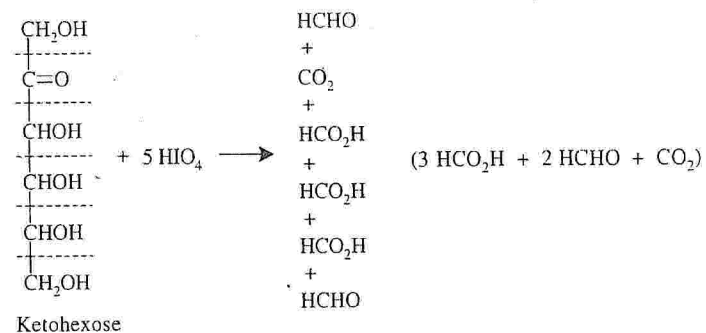
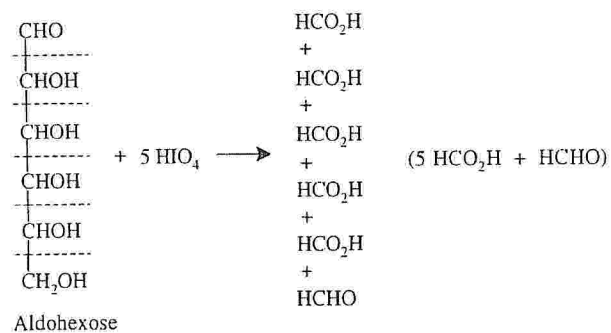


Let us apply this procedure to several examples here while we remember that for every C-C bond that is broken 1 mol of  $\text{HIO}_4$  is consumed.

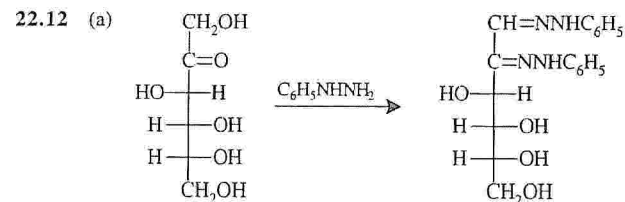
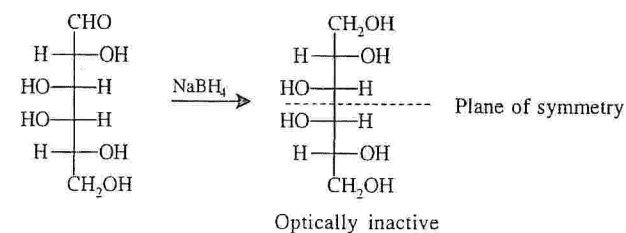
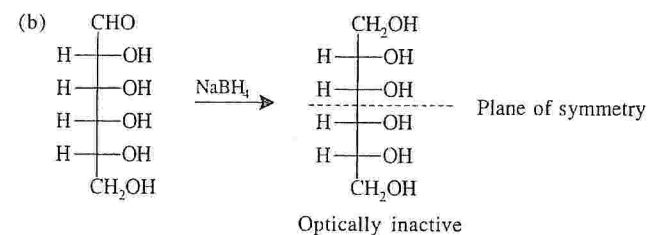




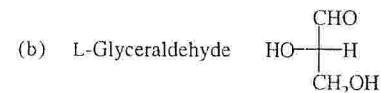
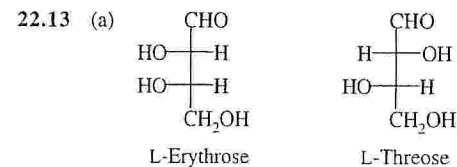
22.10 Oxidation of an aldohexose and a ketohexose would each require 5 mol of  $\text{HIO}_4$  but would give different results.



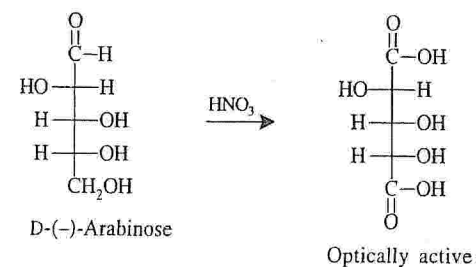
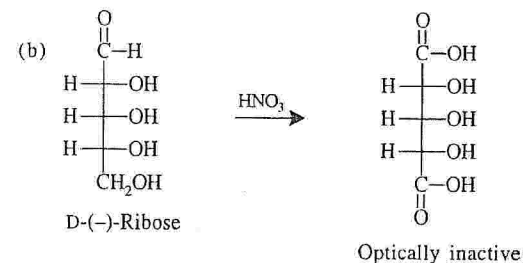
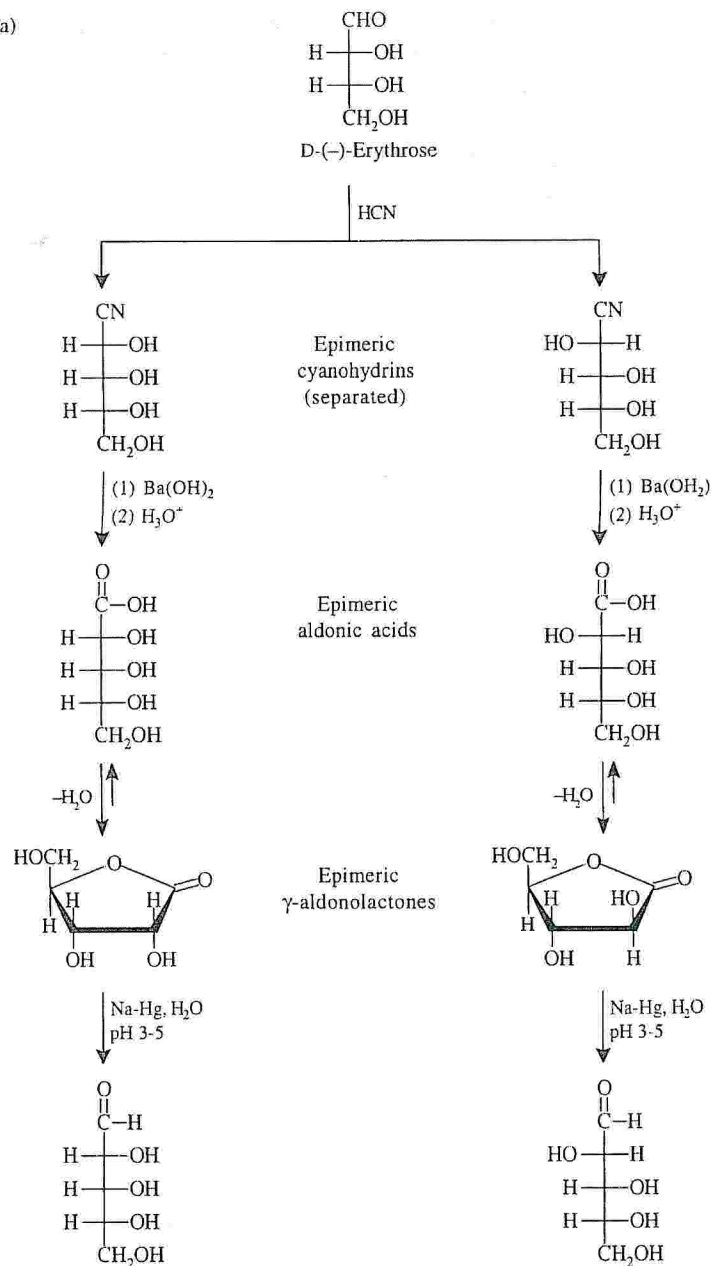
22.11 (a) Yes, D-glucitol would be optically active; only those alditols whose molecules possess a plane of symmetry would be optically inactive.



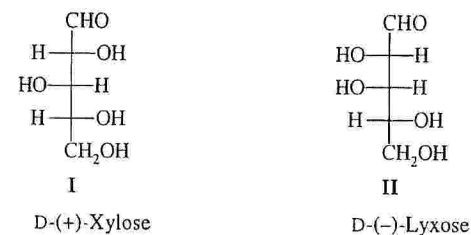
(b) This experiment shows that D-glucose and D-fructose have the same configurations at C3, C4, and C5.



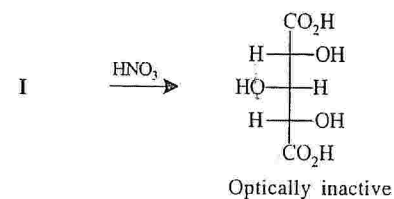
## 22.14 (a)



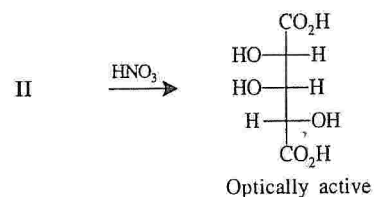
22.15 A Kiliani-Fischer synthesis starting with D-(-)-threose would yield **I** and **II**.



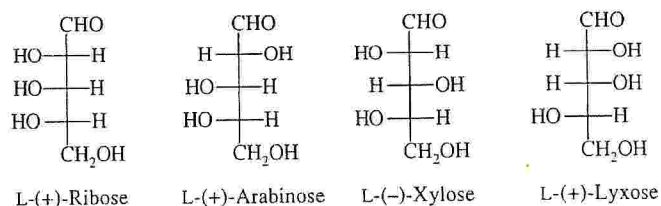
**I** must be D-(+)-xylose because, when oxidized by nitric acid, it yields an optically inactive aldaric acid:



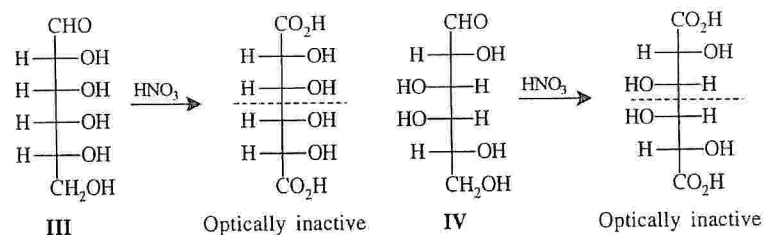
**II** must be D-(-)-lyxose because, when oxidized by nitric acid, it yields an optically active aldaric acid:



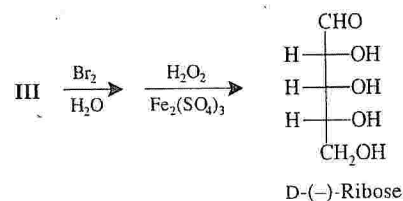
22.16



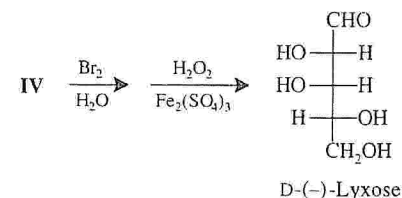
**22.17** Since D-(+)-galactose yields an optically inactive aldaric acid, it must have either structure **III** or structure **IV**.



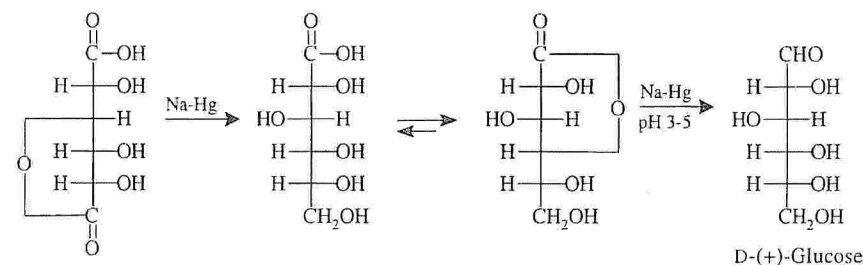
A Ruff degradation beginning with **III** would yield D-(-)-ribose



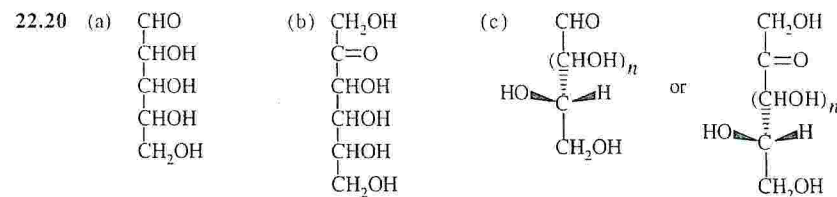
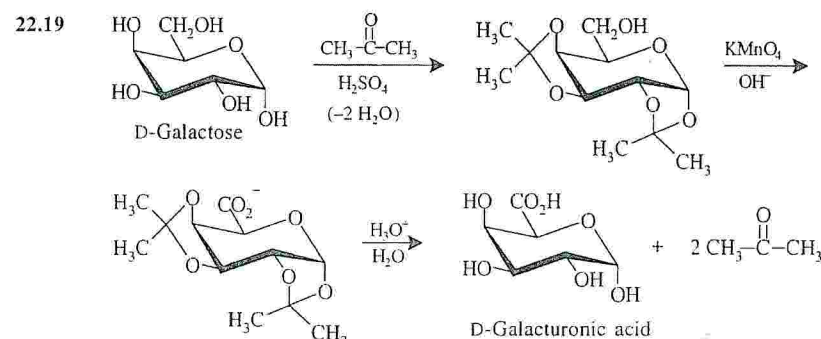
A Ruff degradation beginning with **IV** would yield D-(-)-lyxose: thus, D-(+)-galactose must have structure **IV**.



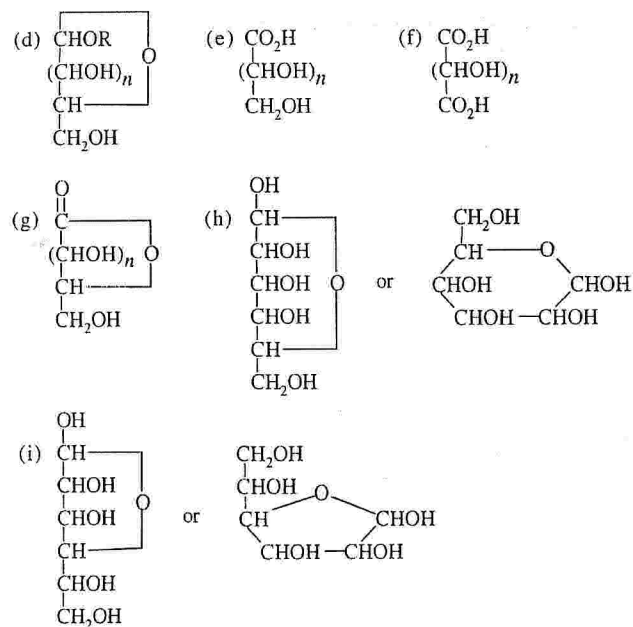
**22.18** D-(+)-glucose, as shown here.



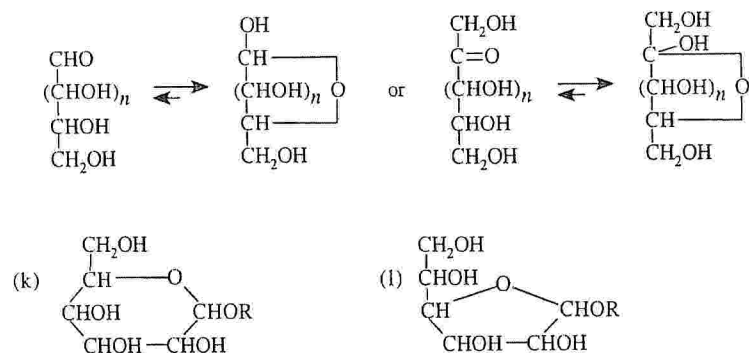
The other  $\gamma$ -lactone of D-glucaric acid



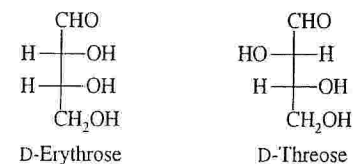




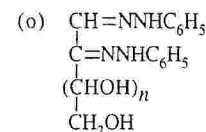
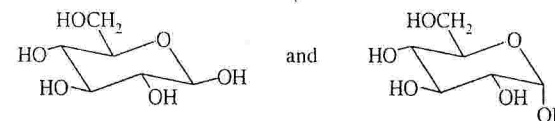
(j) Any sugar that has a free aldehyde or ketone group or one that exists as a cyclic hemiacetal. The following are examples:



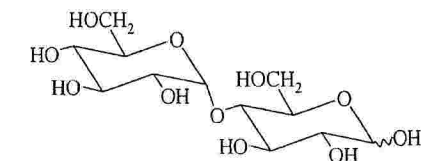
(m) Any two aldoses that differ only in configuration at C2. (See also Section 22.8 for a broader definition.) D-Erythrose and D-threose are examples.



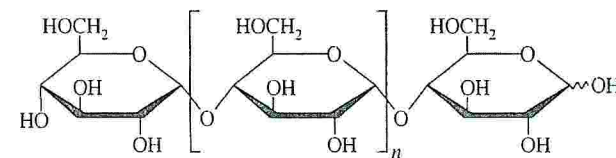
(n) Cyclic sugars that differ only in the configuration of C1. The following are examples:



(p) Maltose is an example:

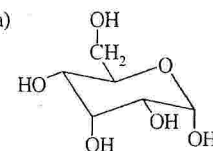


(q) Amylose is an example:

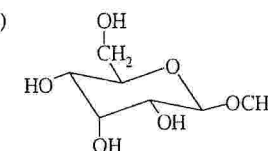


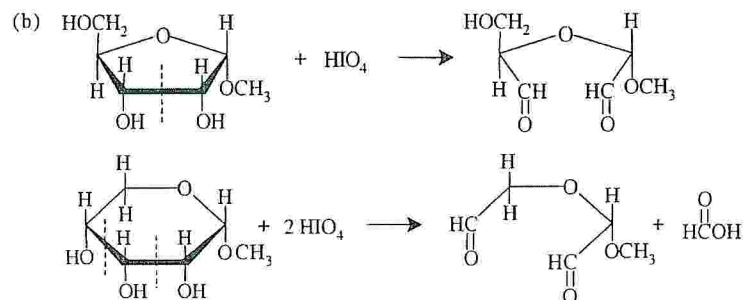
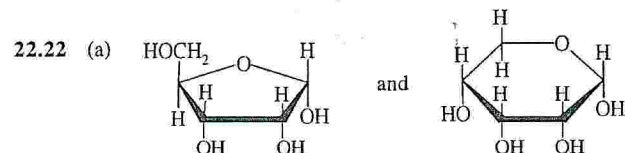
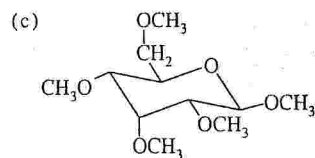
(r) Any sugar in which all potential carbonyl groups are present as acetals (i.e., as glycosides). Sucrose (Section 22.12A) is an example of a nonreducing disaccharide; the methyl D-glucopyranosides (Section 22.4) are examples of nonreducing monosaccharides.

22.21 (a)



(b)

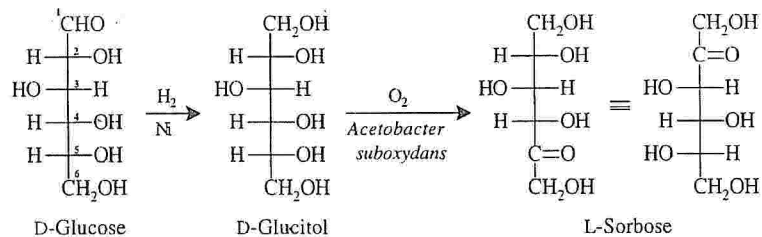




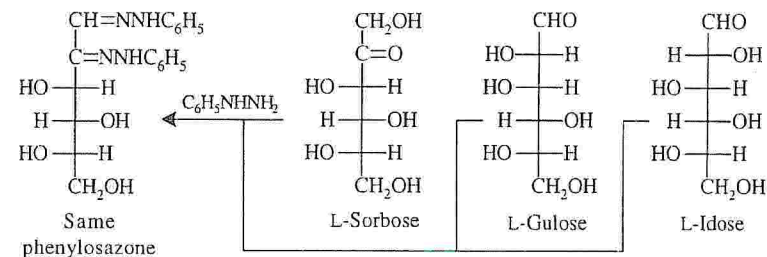
A methyl ribofuranoside would consume only 1 mol of  $\text{HIO}_4$ ; a methyl ribopyranoside would consume 2 mol of  $\text{HIO}_4$  and would also produce 1 mol of formic acid.

22.23 One anomer of D-mannose is dextrorotatory ( $[\alpha]_D^{25} = +29.3^\circ$ ); the other is levorotatory ( $[\alpha]_D^{25} = -17.0^\circ$ ).

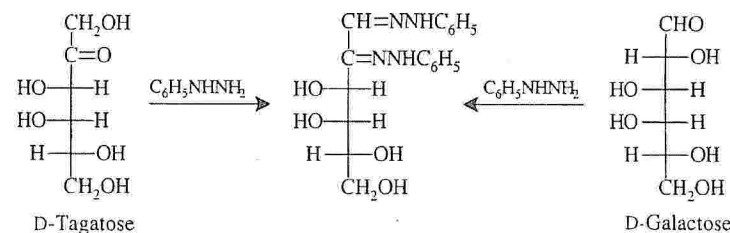
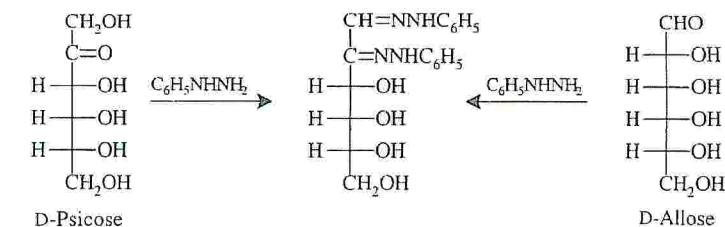
22.24 The microorganism selectively oxidizes the  $-\text{CHOH}$  group of D-glucitol that corresponds to C5 of D-glucose.



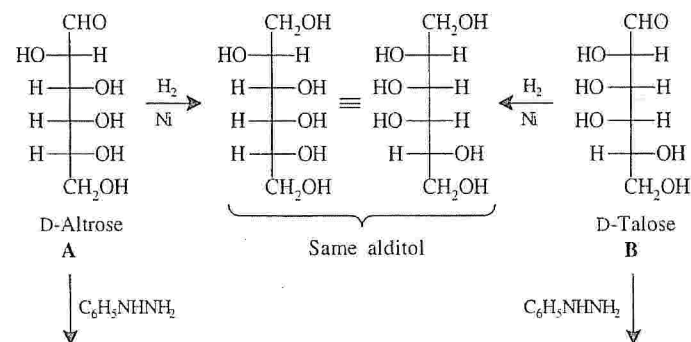
22.25 L-Gulose and L-idose would yield the same phenylosazone as L-sorbose.

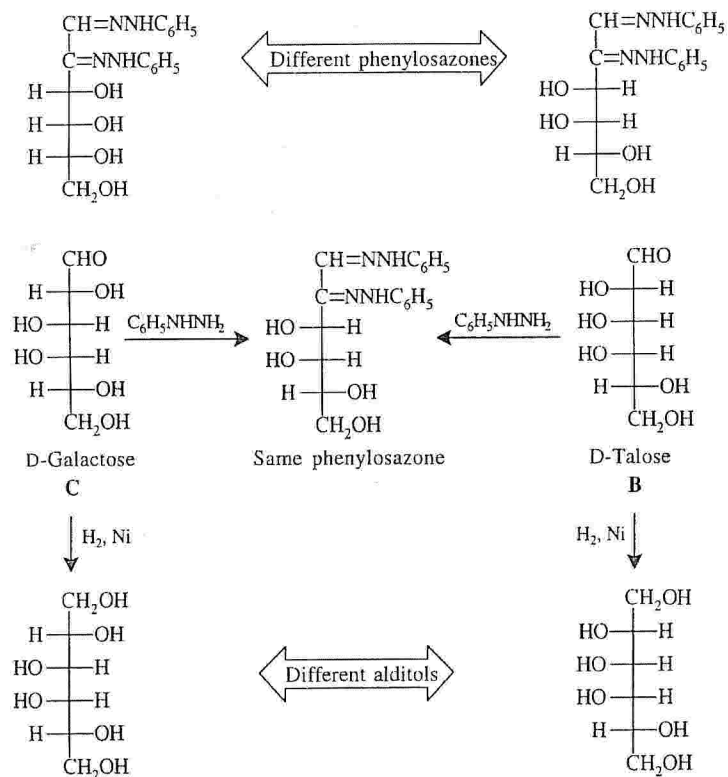


22.26



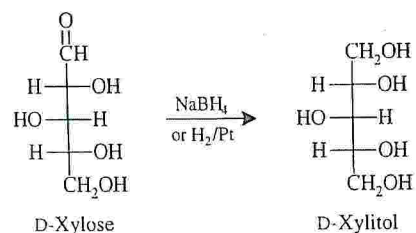
22.27 A is D-altrose, B is D-talose, C is D-galactose.



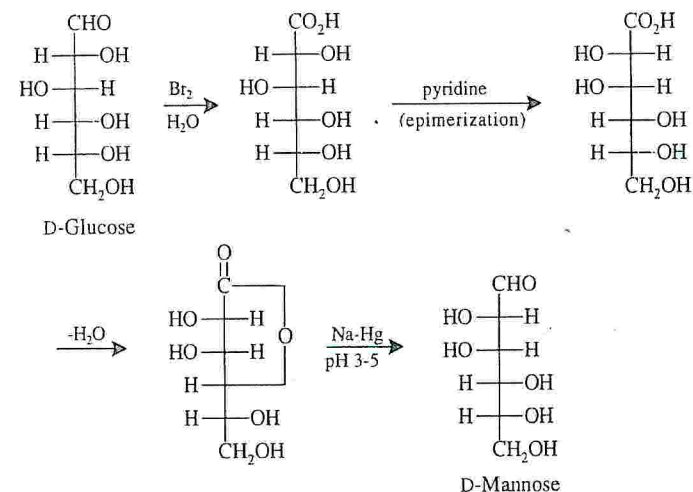


(Note: If we had designated D-talose as A, and D-altrose as B, then C is D-allose).

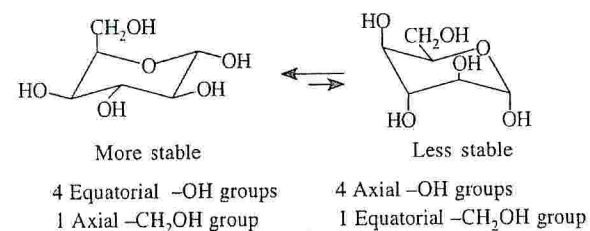
22.28



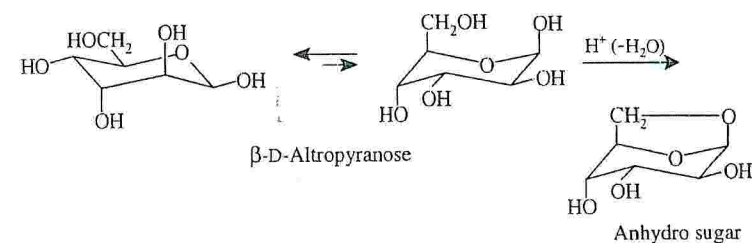
22.29



22.30 The conformation of D-idopyranose with four equatorial  $-\text{OH}$  groups and an axial  $-\text{CH}_2\text{OH}$  group is more stable than the one with four axial  $-\text{OH}$  groups and an equatorial  $-\text{CH}_2\text{OH}$  group.

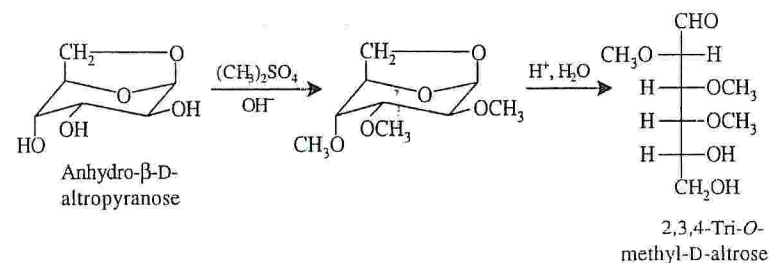


22.31 (a) The anhydro sugar is formed when the axial  $-\text{CH}_2\text{OH}$  group reacts with C1 to form a cyclic acetal.

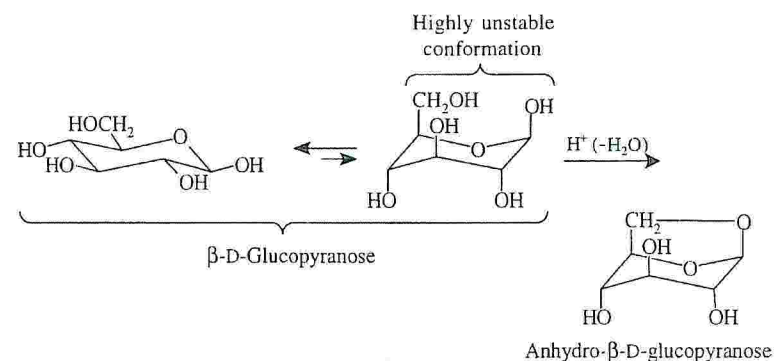


Because the anhydro sugar is an acetal (i.e., an internal glycoside), it is a nonreducing sugar.

Methylation followed by acid hydrolysis converts the anhydro sugar to 2,3,4-tri-*O*-methyl-D-altrose:



(b) Formation of an anhydro sugar requires that the monosaccharide adopt a chair conformation with the  $-\text{CH}_2\text{OH}$  group axial. With  $\beta$ -D-altropyranose this requires that two  $-\text{OH}$  groups be axial as well. With  $\beta$ -D-glucopyranose, however, it requires that all four  $-\text{OH}$  groups become axial and thus that the molecule adopt a very unstable conformation:



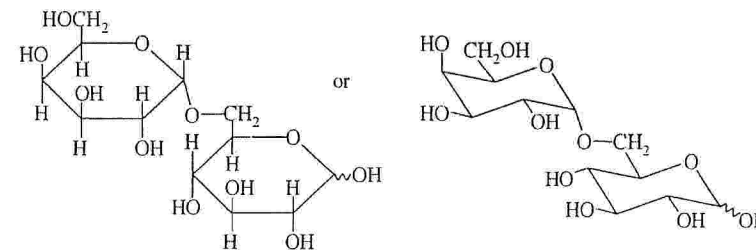
- 22.32**
- The molecular formula and the results of acid hydrolysis show that lactose is a disaccharide composed of D-glucose and D-galactose. The fact that lactose is hydrolyzed by a  $\beta$ -galactosidase indicates that galactose is present as a glycoside and that the glycosidic linkage is beta to the galactose ring.
  - That lactose is a reducing sugar, forms a phenylosazone, and undergoes mutarotation indicates that one ring (presumably that of D-glucose) is present as a hemiacetal and thus is capable of existing to a limited extent as an aldehyde.
  - This experiment confirms that the D-glucose unit is present as a cyclic hemiacetal and that the D-galactose unit is present as a cyclic glycoside.

4. That 2,3,4,6-tetra-*O*-methyl-D-galactose is obtained in this experiment indicates (by virtue of the free  $-\text{OH}$  at C5) that the galactose ring of lactose is present as a pyranoside. That the methylated gluconic acid obtained from this experiment has a free  $-\text{OH}$  group at C4 indicates that the C4 oxygen atom of the glucose unit is connected in a glycosidic linkage to the galactose unit.

Now only the size of the glucose ring remains in question, and the answer to this is provided by experiment 5.

5. That methylation of lactose and subsequent hydrolysis gives 2,3,6-tri-*O*-methyl-D-glucose—that it gives a methylated glucose derivative with a free  $-\text{OH}$  at C4 and C5—demonstrates that the glucose ring is present as a pyranose. (We know already that the oxygen at C4 is connected in a glycosidic linkage to the galactose unit; thus, a free  $-\text{OH}$  at C5 indicates that the C5 oxygen atom is a part of the hemiacetal group of the glucose unit and that the ring is six membered.)

### 22.33



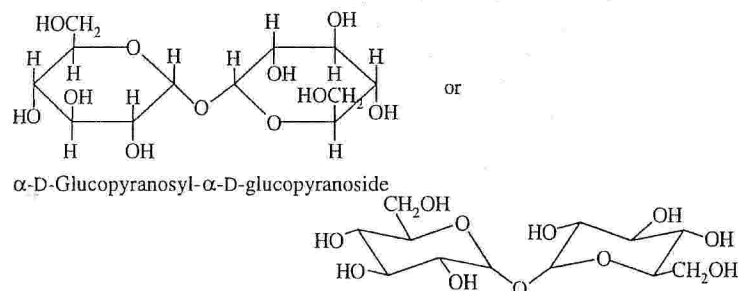
6-*O*-( $\alpha$ -D-Galactopyranosyl)-D-glucopyranose

We arrive at this conclusion from the data given:

- That melibiose is a reducing sugar and that it undergoes mutarotation and forms a phenylosazone indicate that one monosaccharide is present as a cyclic hemiacetal.
- That acid hydrolysis gives D-galactose and D-glucose indicates that melibiose is a disaccharide composed of one D-galactose unit and one D-glucose unit. That melibiose is hydrolyzed by an  $\alpha$ -galactosidase suggests that melibiose is an  $\alpha$ -D-galactosyl-D-glucose.
- Oxidation of melibiose to melibionic acid and subsequent hydrolysis to give D-galactose and D-gluconic acid confirms that the glucose unit is present as a cyclic hemiacetal and that the galactose unit is present as a glycoside. (Had the reverse been true, this experiment would have yielded D-glucose and D-galactonic acid.)  
Methylation and hydrolysis of melibionic acid produces 2,3,4,6-tetra-*O*-methyl-D-galactose and 2,3,4,5-tetra-*O*-methyl-D-gluconic acid. Formation of the first product—a galactose derivative with a free  $-\text{OH}$  at C5—demonstrates that the galactose ring is six membered; formation of the second product—a gluconic acid derivative with a free  $-\text{OH}$  at C6—demonstrates that the oxygen at C6 of the glucose unit is joined in a glycosidic linkage to the galactose unit.
- That methylation and hydrolysis of melibiose gives a glucose derivative (2,3,4-tri-*O*-methyl-D-glucose) with free  $-\text{OH}$  groups at C5 and C6 shows that the glucose ring is also six membered. Melibiose is, therefore, 6-*O*-( $\alpha$ -D-galactopyranosyl)-D-glucopyranose.



22.34 Trehalose has the following structure:



We arrive at this structure in the following way:

1. Acid hydrolysis shows that trehalose is a disaccharide consisting only of D-glucose units.
2. Hydrolysis by  $\alpha$ -glucosidases and not by  $\beta$ -glucosidases shows that the glycosidic linkages are alpha.
3. That trehalose is a nonreducing sugar, that it does not form a phenylosazone, and that it does not react with bromine water indicate that no hemiacetal groups are present. This means that C1 of one glucose unit and C1 of the other must be joined in a glycosidic linkage. Fact 2 (just cited) indicates that this linkage is alpha to each ring.
4. That methylation of trehalose followed by hydrolysis yields only 2,3,4,6-tetra-O-methyl-D-glucose demonstrates that both rings are six membered.

22.35 (a) Tollens' reagent or Benedict's reagent will give a positive test with D-glucose but will give no reaction with D-glucitol.

(b) D-Glucaric acid will give an acidic aqueous solution that can be detected with blue litmus paper. D-Glucitol will give a neutral aqueous solution.

(c) D-Glucose will be oxidized by bromine water and the red brown color of bromine will disappear. D-Fructose will not be oxidized by bromine water since it does not contain an aldehyde group.

(d) Nitric acid oxidation will produce an *optically active* aldaric acid from D-glucose but an *optically inactive* aldaric acid will result from D-galactose.

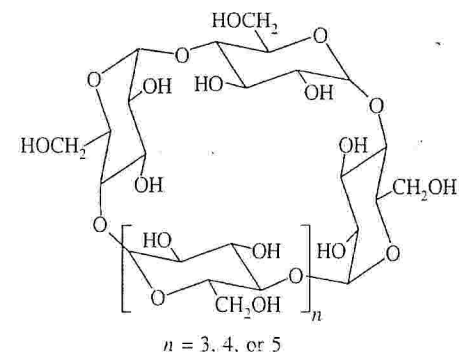
(e) Maltose is a reducing sugar and will give a positive test with Tollens' or Benedict's solution. Sucrose is a nonreducing sugar and will not react.

(f) Maltose will give a positive Tollens' or Benedict's test; maltonic acid will not.

(g) 2,3,4,6-Tetra-O-methyl- $\beta$ -D-glucopyranose will give a positive test with Tollens' or Benedict's solution; methyl  $\beta$ -D-glucopyranoside will not.

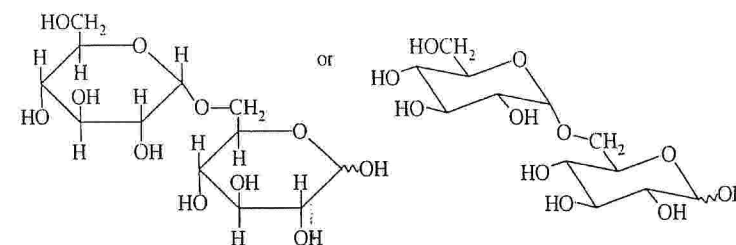
(h) Periodic acid will react with methyl  $\alpha$ -D-ribofuranoside because it has hydroxyl groups on adjacent carbons. Methyl 2-deoxy- $\alpha$ -D-ribofuranoside will not react.

22.36 That the Schardinger dextrins are nonreducing shows that they have no free aldehyde or hemiacetal groups. This lack of reaction strongly suggests the presence of a *cyclic* structure. That methylation and subsequent hydrolysis yields only 2,3,6-tri-O-methyl-D-glucose indicates that the glycosidic linkages all involve C1 of one glucose unit and C4 of the next. That  $\alpha$ -glucosidases cause hydrolysis of the glycosidic linkages indicates that they are  $\alpha$ -glycosidic linkages. Thus, we are led to the following general structure.



*Note:* Schardinger dextrins are extremely interesting compounds. They are able to form complexes with a wide variety of compounds by incorporating these compounds in the cavity in the middle of the cyclic dextrin structure. Complex formation takes place, however, only when the cyclic dextrin and the guest molecule are the right size. Anthracene molecules, for example, will fit into the cavity of a cyclic dextrin with eight glucose units but will not fit into one with seven. For more information about these fascinating compounds, see Bergeron, R. J., "Cycloamyloses," *J. Chem. Educ.*, **1977**, *54*, 204-207.

22.37 Isomaltose has the following structure:



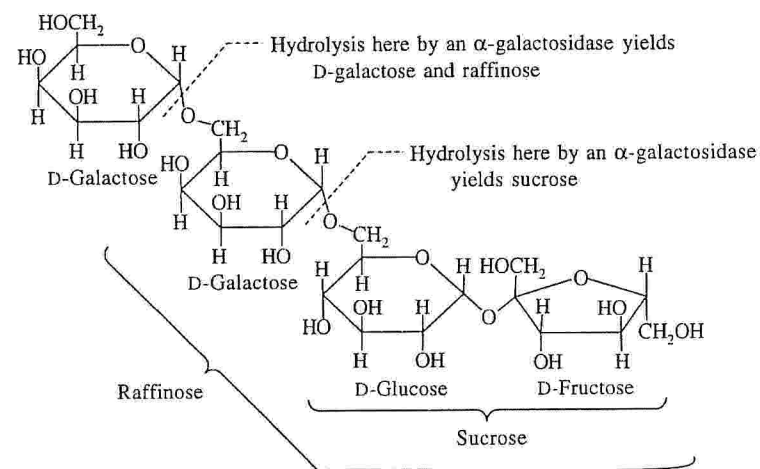
(1) The acid and enzymic hydrolysis experiments tell us that isomaltose has two glucose units linked by an  $\alpha$  linkage.

(2) That isomaltose is a reducing sugar indicates that one glucose unit is present as a cyclic hemiacetal.

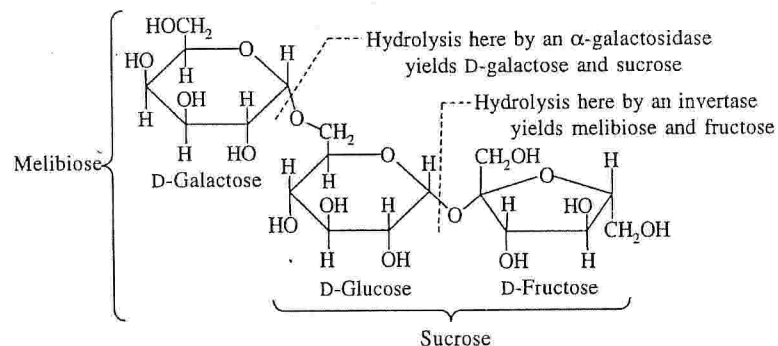
(3) Methylation of isomaltonic acid followed by hydrolysis gives us information about the size of the nonreducing pyranoside ring and about its point of attachment to the reducing ring. The formation of the first product (2,3,4,6-tetra-*O*-methyl-D-glucose)—a compound with an -OH at C5—tells us that the nonreducing ring is present as a pyranoside. The formation of 2,3,4,5-tetra-*O*-methyl-D-gluconic acid—a compound with an -OH at C6—shows that the nonreducing ring is linked to C6 of the reducing ring.

(4) Methylation of maltose itself tells the size of the reducing ring. That 2,3,4-tri-*O*-methyl-D-glucose is formed shows that the reducing ring is also six membered; we know this because of the free -OH at C5.

**22.38** Stachyose has the following structure:

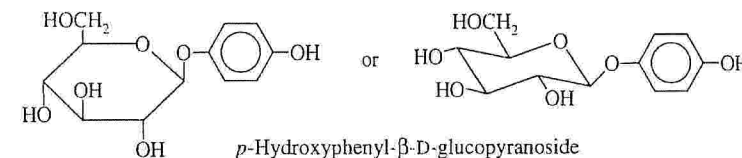


Raffinose has the following structure:

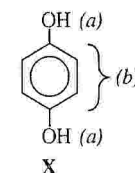


The enzymic hydrolyses (as just indicated) give the basic structure of stachyose and raffinose. The only remaining question is the ring size of the first galactose unit of stachyose. That methylation of stachyose and subsequent hydrolysis yields 2,3,4,6-tetra-*O*-methyl-D-galactose establishes that this ring is a pyranoside.

**22.39** Arbutin has the following structure:

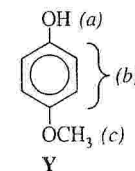


Compounds **X**, **Y**, and **Z** are hydroquinone, *p*-methoxyphenol, and *p*-dimethoxybenzene, respectively.



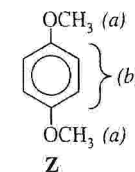
Hydroquinone

(a) Singlet  $\delta$  7.9 [2H]  
(b) Singlet  $\delta$  6.8 [4H]



*p*-Methoxyphenol

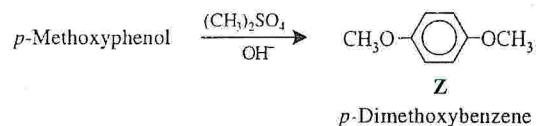
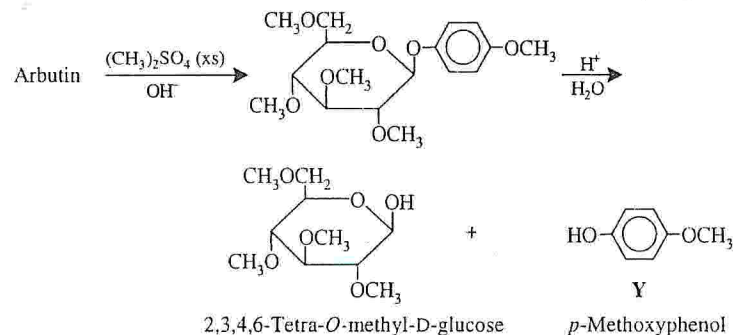
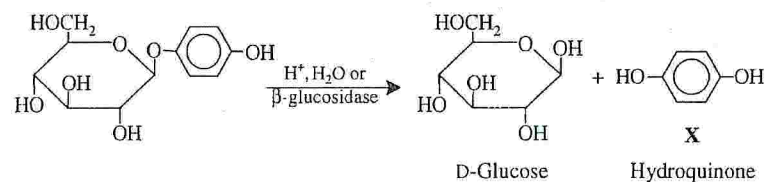
(a) Singlet  $\delta$  4.8 [1H]  
(b) Multiplet  $\delta$  6.8 [4H]  
(c) Singlet  $\delta$  3.9 [3H]



*p*-Dimethoxybenzene

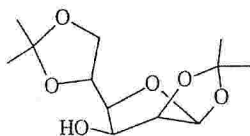
(a) Singlet  $\delta$  3.75 [6H]  
(b) Singlet  $\delta$  6.8 [4H]

The reactions that take place are the following:

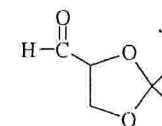


- 22.40** Aldotetrose **B** must be D-threose because the alditol derived from it (D-threitol) is optically active (the alditol from D-erythrose, the other possible D-aldotetrose, would be meso). Due to rotational symmetry, however, the alditol from **B** (D-threitol) would produce only two  $^{13}\text{C}$  NMR signals. Compounds **A-F** are thus in the family of aldoses stemming from D-threose. Since reduction of aldopentose **A** produces an optically inactive alditol, **A** must be D-xylose. The two diastereomeric aldohexoses **C** and **D** produced from **A** by a Kiliani-Fischer synthesis must therefore be D-idose and D-gulose, respectively. **E** and **F** are the alditols derived from **C** and **D**, respectively. Alditol **E** would produce only three  $^{13}\text{C}$  NMR signals due to rotational symmetry while **F** would produce six signals.

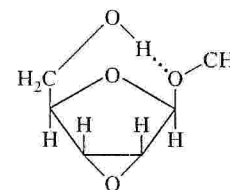
- 22.41** There are four closely spaced upfield alkyl signals in the  $^{13}\text{C}$  NMR spectrum ( $\delta 26.5$ ,  $\delta 25.6$ ,  $\delta 24.9$ ,  $\delta 24.2$ ), corresponding to the four methyls of the two acetonide protecting groups. (The compound is, therefore, the 1,2,5,6-bis-acetonide of mannofuranose, below.)



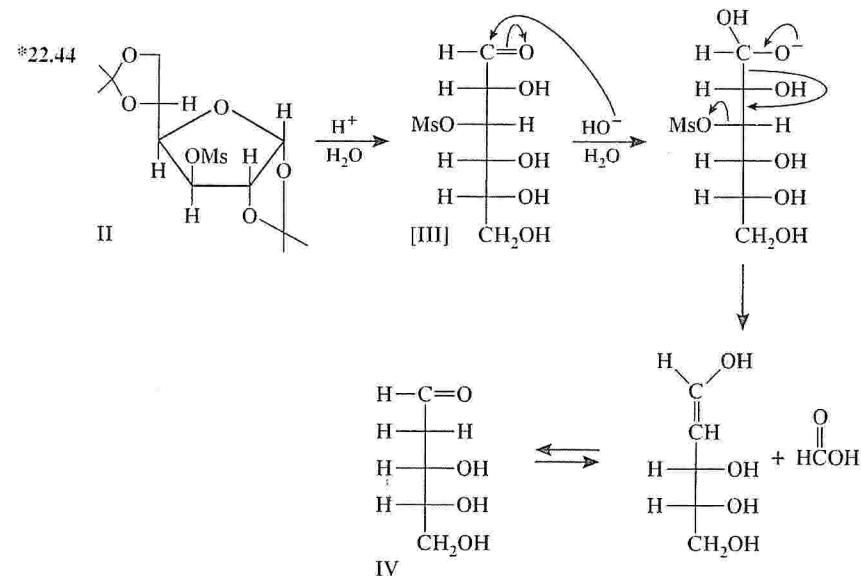
- 22.42** The final product is the acetonide of glyceraldehyde (below); two molar equivalents are formed from each molar equivalent of the 1,2,5,6-bis-acetonide of mannitol.



- \*22.43** The  $\beta$ -anomer can hydrogen bond intramolecularly, as in:

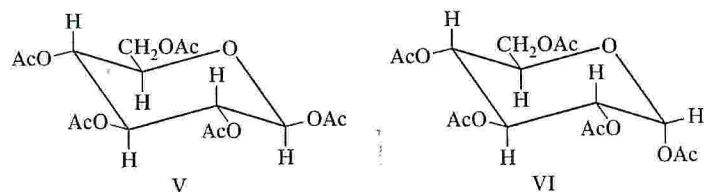


In contrast, the  $\alpha$ -anomer can only hydrogen bond intermolecularly.





- \*22.45 (a) The proton at C1. (b) Because of the single neighboring hydrogen (at C2). (c and d).



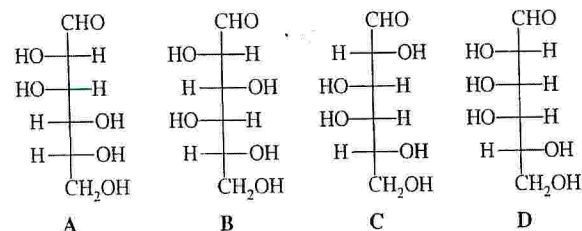
## QUIZ

- 22.1 Supply the appropriate structural formula or complete the partial formula for each of the following:

|               |                                                                                                                                                    |                                                                                                                                 |           |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-----------|
| (a)           | (b)                                                                                                                                                | (c)                                                                                                                             | (d)       |
|               | $\begin{array}{c} \text{CHO} \\   \\ -\text{C}- \\   \\ -\text{C}- \\   \\ -\text{C}- \\   \\ -\text{C}- \\   \\ \text{CH}_2\text{OH} \end{array}$ | $\begin{array}{c} \text{CHO} \\   \\ -\text{C}- \\   \\ -\text{C}- \\   \\ -\text{C}- \\   \\ \text{CH}_2\text{OH} \end{array}$ |           |
| A ketotetrose | A D-sugar                                                                                                                                          | An L-sugar                                                                                                                      | An aldose |

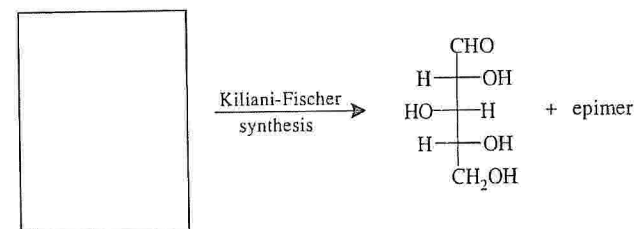
|                                                                                                                                                                                                    |                           |                          |                                                      |                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|--------------------------|------------------------------------------------------|-----------------------------------------------------------|
| $\begin{array}{c} \text{CHO} \\   \\ \text{H}-\text{OH} \\   \\ \text{H}-\text{OH} \\   \\ \text{HO}-\text{H} \\   \\ \text{H}-\text{OH} \\   \\ \text{CH}_2\text{OH} \end{array}$ <p>D-Gulose</p> | (e)                       | (f)                      | (g)                                                  | (h)                                                       |
|                                                                                                                                                                                                    |                           |                          | The compound that gives the same osazone as D-gulose | The compound that gives the same aldaric acid as D-gulose |
|                                                                                                                                                                                                    | $\alpha$ -D-Gulo-pyranose | $\beta$ -D-Gulo-pyranose |                                                      |                                                           |

- 22.2 Which of the following monosaccharides yields an optically inactive alditol on  $\text{NaBH}_4$  reduction?

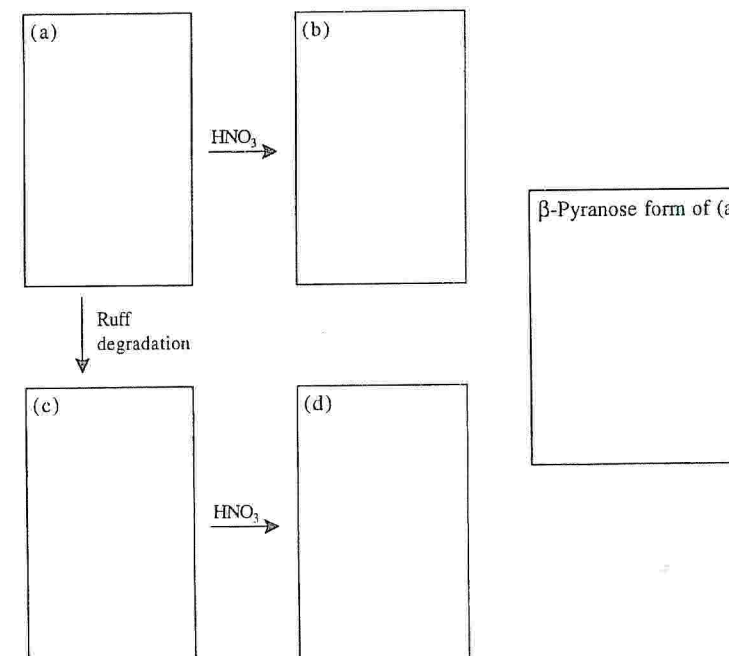


Answer:

- 22.3 Give the structural formula of the monosaccharide that you could use as starting material in the Kiliani-Fischer synthesis of the following compound:



- 22.4 The D-aldopentose, (a), is oxidized to an aldaric acid, (b), which is optically active. Compound (a) undergoes a Ruff degradation to form an aldotetrose, (c), which undergoes oxidation to an optically inactive aldaric acid, (d). Supply the reagents for these transformations and the structural formulas of (a), (b), (c), and (d).

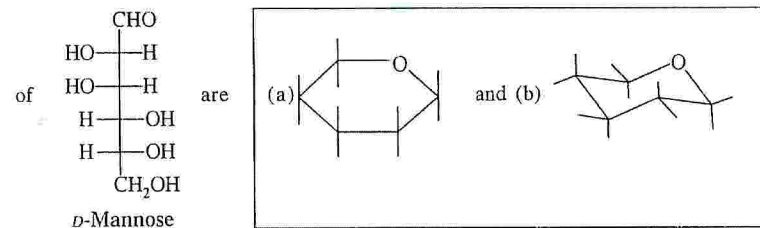


- 22.5 Give the structural formula of the  $\beta$ -pyranose form of (a) in the space just given.



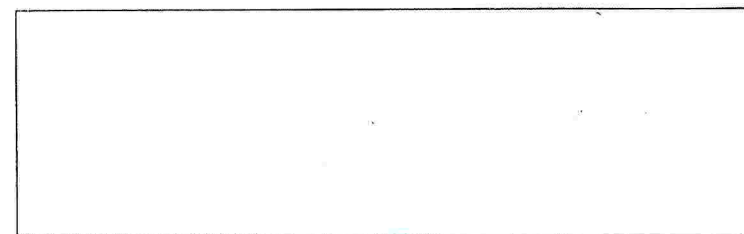
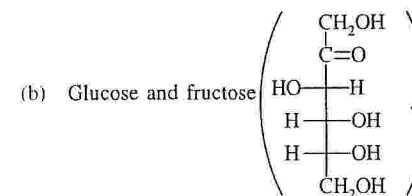
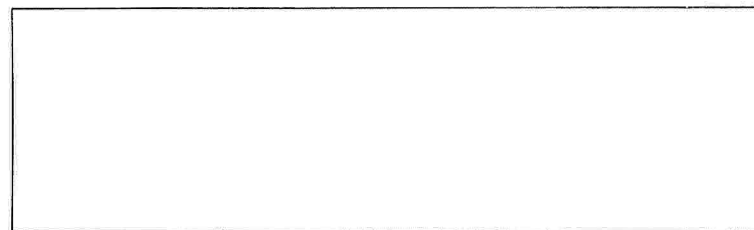
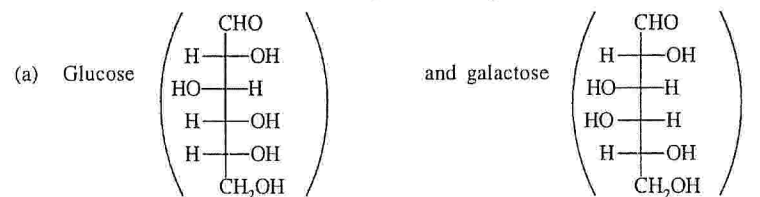
- 22.6 Complete the following skeletal formulas and statements by filling in the blanks and circling the words that make the statements true.

The Haworth and conformational formulas of the  $\beta$ -cyclic hemiacetal



This cyclic hemiacetal is (c) reducing, nonreducing; on reaction with  $\text{Br}_2/\text{H}_2\text{O}$  it gives an optically (d) active, inactive (e) aldaric, aldonic acid. On reaction with dilute  $\text{HNO}_3$  it gives an optically (f) active, inactive (g) aldaric, aldonic acid. Reaction of the cyclic hemiacetal with (h) converts it into an optically (i) active, inactive alditol.

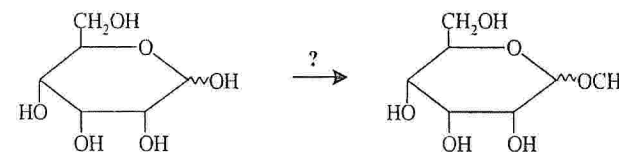
- 22.7 Outline chemical tests that would allow you to distinguish between:



- 22.8 Hydrolysis of (+)-sucrose (ordinary table sugar) yields

- (a) *D*-glucose  
(b) *D*-mannose  
(c) *D*-fructose  
(d) *D*-galactose  
(e) More than one of the above.

- 22.9 Select the reagent needed to perform the following transformation:

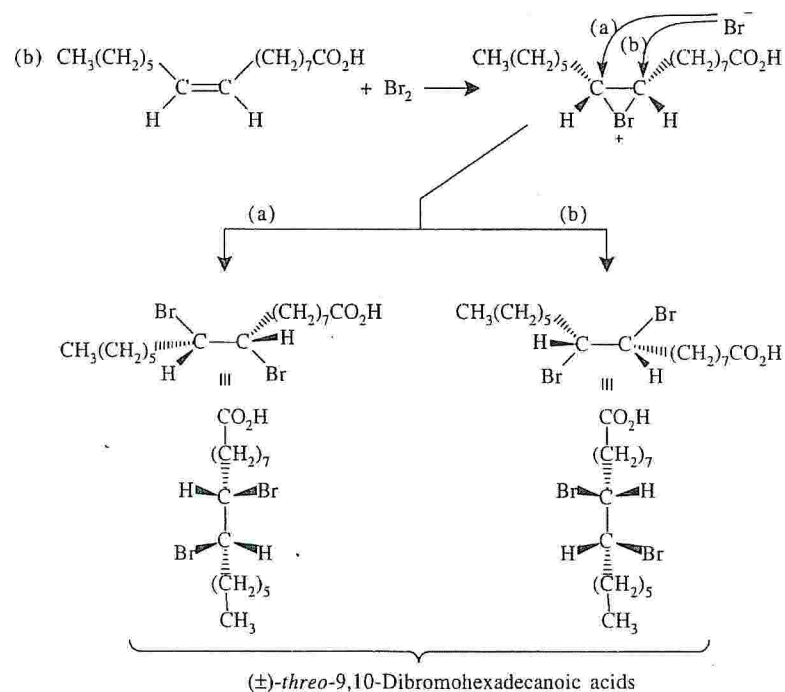
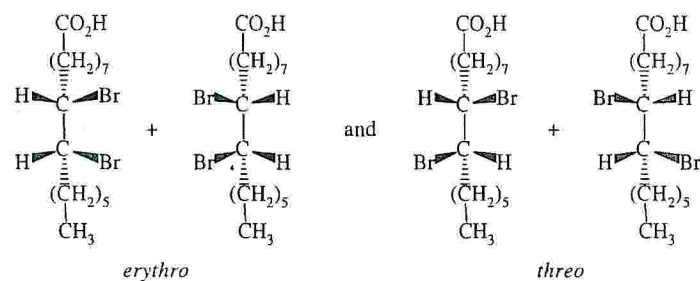


- (a)  $\text{CH}_3\text{OH}, \text{KOH}$  (b)  $(\text{CH}_3\text{C}(=\text{O}))_2\text{O}$  (c)  $(\text{CH}_3)_2\text{SO}_4, \text{OH}^-$   
(d)  $\text{CH}_3\text{OH}, \text{HCl}$  (e)  $\text{CH}_3\text{OCH}_3, \text{HCl}$

# 23 LIPIDS

## SOLUTIONS TO PROBLEMS

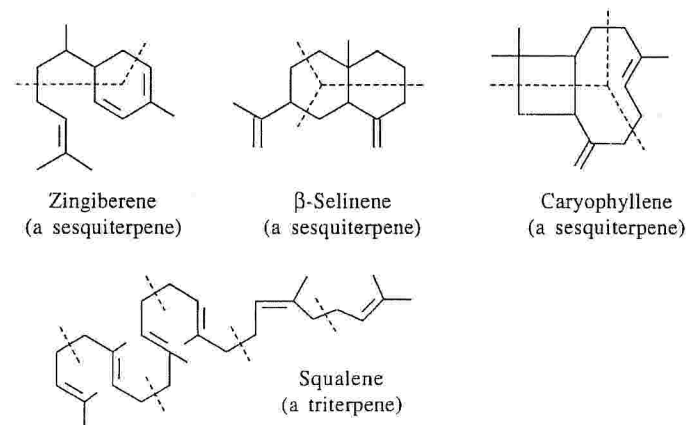
23.1 (a) There are two sets of enantiomers, giving a total of four stereoisomers:



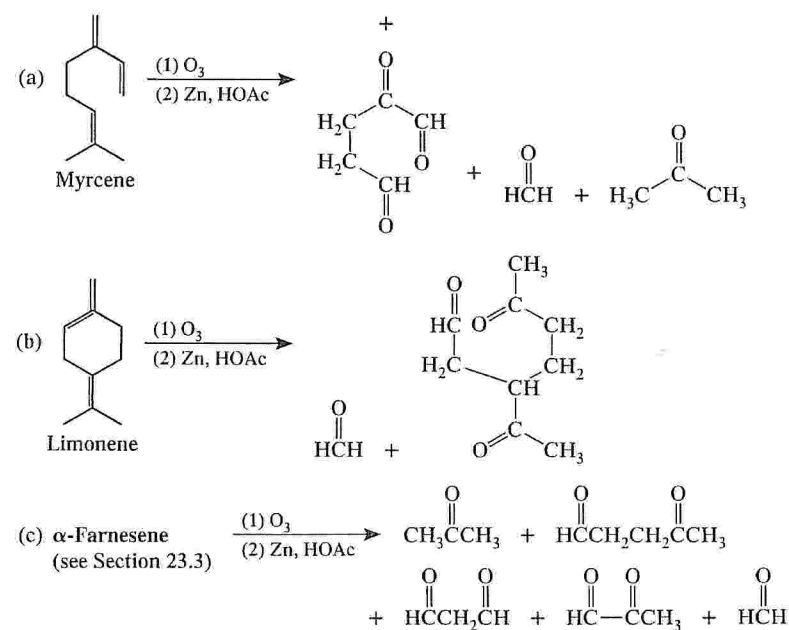
Formation of a bromonium ion at the other face of palmitoleic acid gives a result such that the *threo* enantiomers are the only products formed (obtained as a racemic modification).

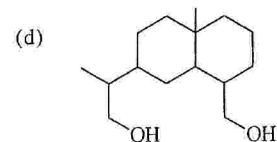
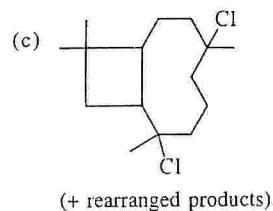
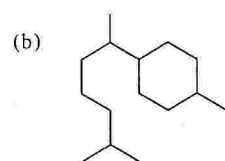
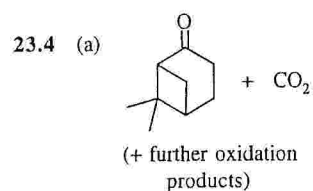
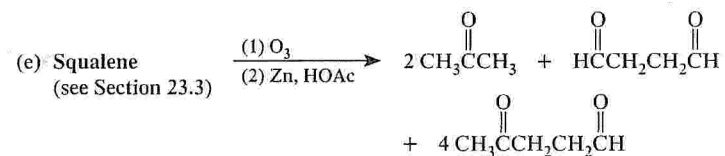
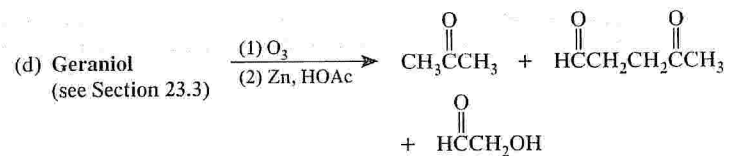
The designations *erythro* and *threo* come from the names of the sugars called *erythrose* and *threose* (Section 22.9A).

23.2

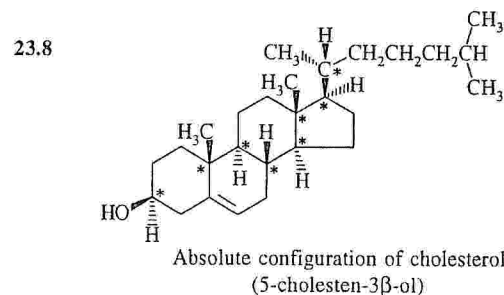
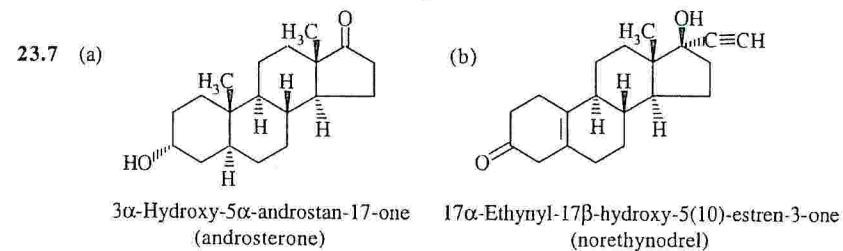
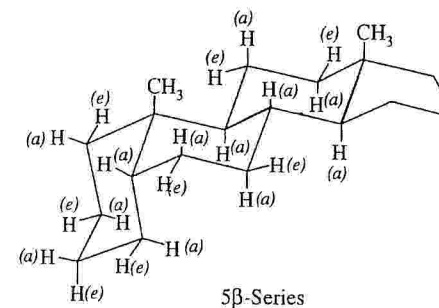
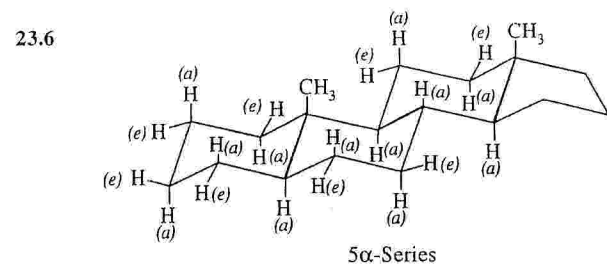


23.3

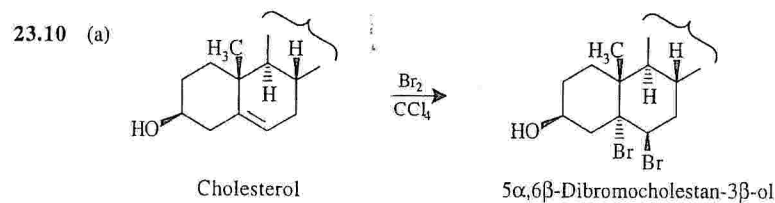


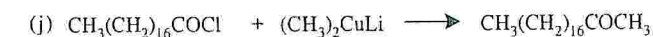
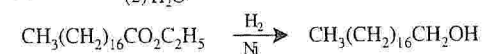
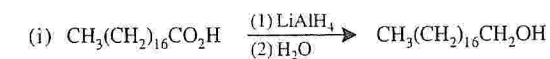
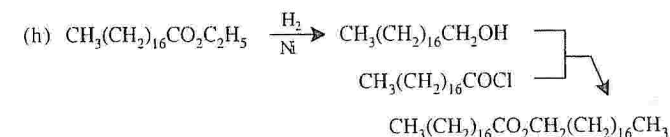
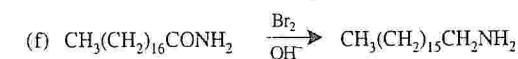
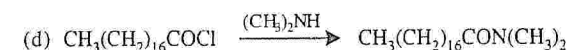
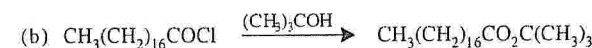
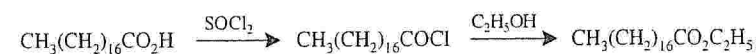
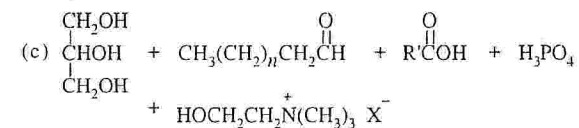
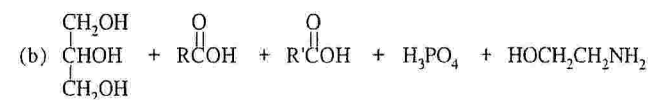
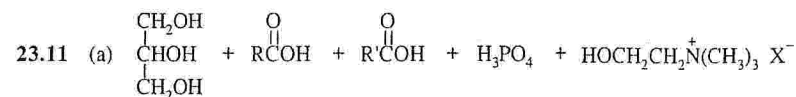
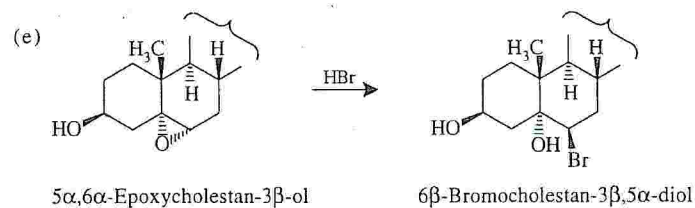
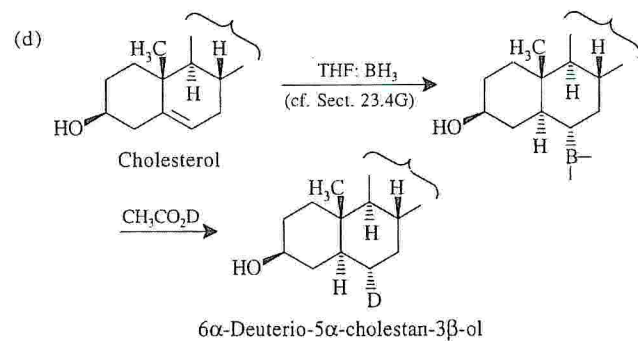
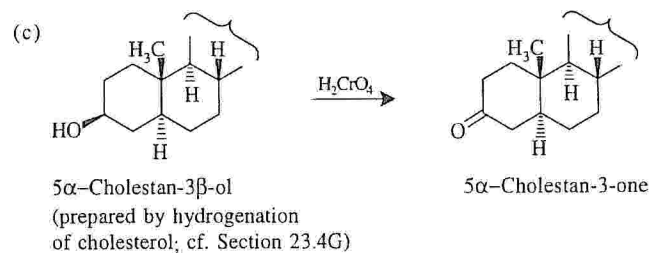
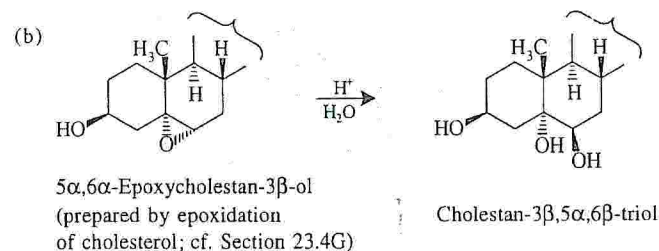


23.5 Br<sub>2</sub> in CCl<sub>4</sub> or KMnO<sub>4</sub> in H<sub>2</sub>O at room temperature. Either reagent would give a positive result with geraniol and a negative result with menthol.

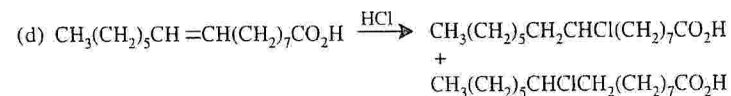
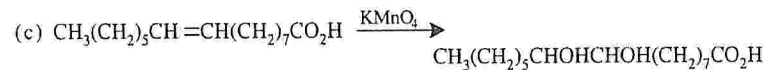
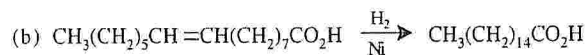
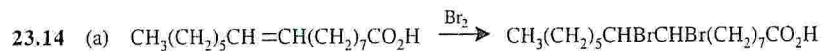
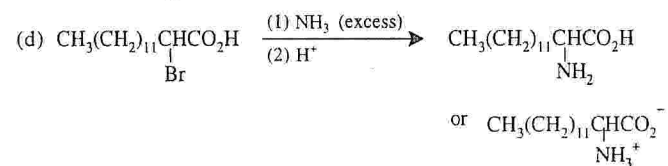
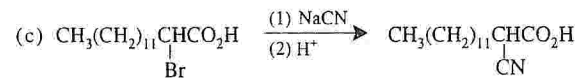
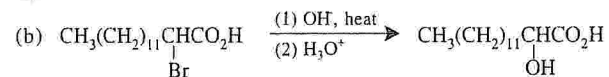
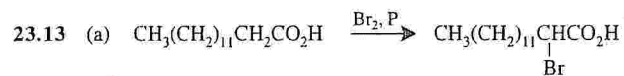
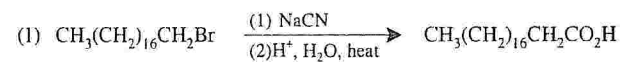
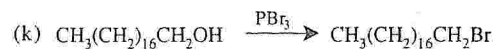


23.9 Estrone and estradiol are *phenols* and thus are soluble in aqueous sodium hydroxide. Extraction with aqueous sodium hydroxide separates the estrogens from the androgens.

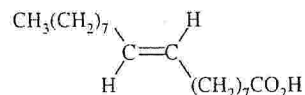




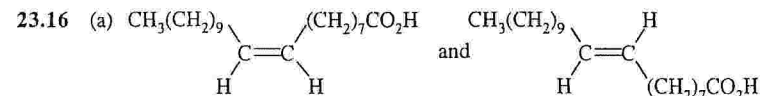




23.15 Elaidic acid is *trans*-9-octadecenoic acid:



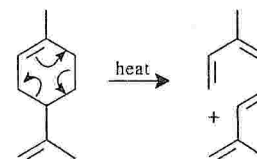
It is formed by the isomerization of oleic acid.



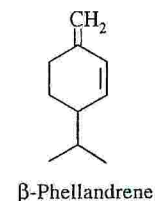
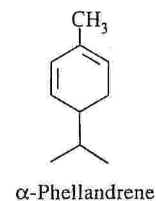
(b) Infrared spectroscopy

(c) A peak in the 675–730-cm<sup>-1</sup> region would indicate that the double bond is *cis*; a peak in the 960–975-cm<sup>-1</sup> region would indicate that it is *trans*.

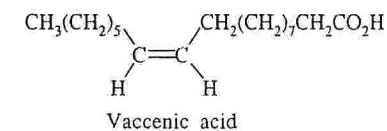
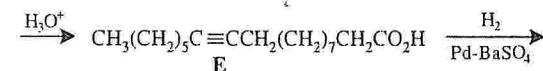
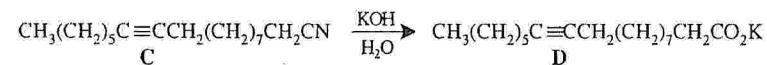
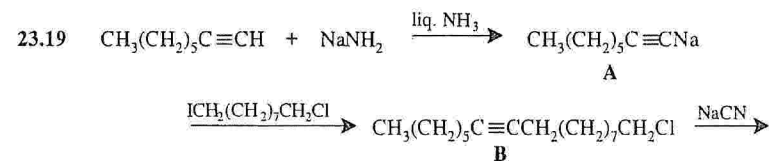
23.17 A reverse Diels-Alder reaction takes place.

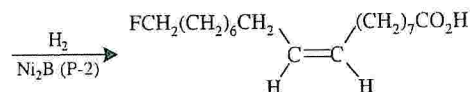
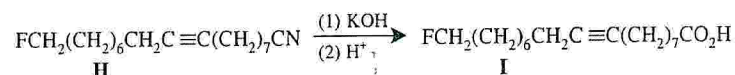
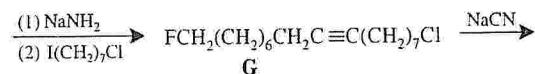
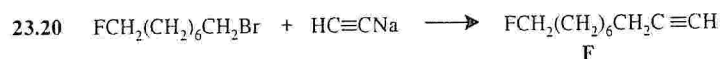


23.18

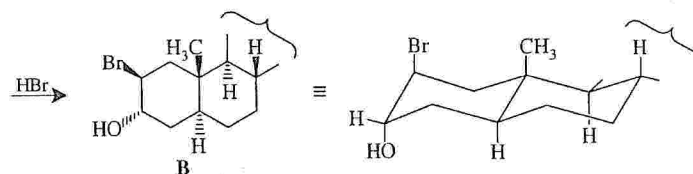
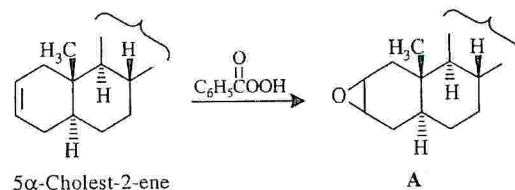


Note: On permanganate oxidation, the =CH<sub>2</sub> group of  $\beta$ -phellandrene is converted to CO<sub>2</sub> and thus is not detected in the reaction.

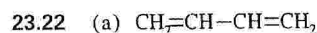




23.21



Here we find that epoxidation takes place at the less hindered  $\alpha$  face (cf. Section 23.4G). Ring opening by HBr takes place in an anti fashion to give a product with diaxial substituents.



(b)  $\text{OH}^-$  (Removal of the  $\alpha$  hydrogen atom allows isomerization to the more stable compound with a trans ring junction.)

(c)  $\text{LiAlH}_4$

(d)  $\text{H}_3\text{O}^+$  and heat. (Hydrolysis of the enol ether is followed by dehydration of one alcohol group.)

(e)  $\text{HCO}_2\text{C}_2\text{H}_5$ ,  $\text{C}_2\text{H}_5\text{ONa}$

(f)  $\text{OsO}_4$ , then  $\text{NaHSO}_3$

(g)  $\text{CH}_3\text{C}(=\text{O})\text{CH}_3$ ,  $\text{H}^+$

(h)  $\text{H}_2$ , Pd catalyst

(i)  $\text{H}_3\text{O}^+$ ,  $\text{H}_2\text{O}$

(j)  $\text{HIO}_4$

(k) Base and heat. (This reaction is an aldol condensation.)

(l) and (m)  $\text{Na}_2\text{CrO}_4$ ,  $\text{CH}_3\text{CO}_2\text{H}$  to oxidize the aldehyde to an acid, followed by esterification.

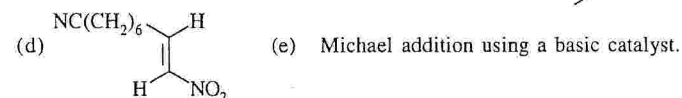
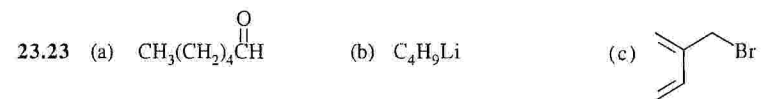
(n)  $\text{H}_2$  and Pt. (Hydrogen addition takes place from the less hindered  $\alpha$  face of the molecule.)

(o), (p), and (q)  $\text{NaBH}_4$  to reduce the keto group;  $\text{OH}^-$ ,  $\text{H}_2\text{O}$  to hydrolyze the ester; and acetic anhydride to esterify the OH at the 3-position.

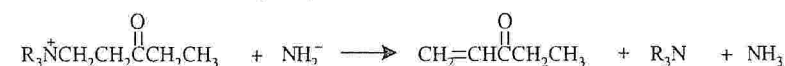
(r) and (s)  $\text{SOCl}_2$  to make the acid chloride, followed by treatment with  $(\text{CH}_3)_2\text{Cd}$ .

(t)  $\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_2\text{MgBr}$ , followed by  $\text{H}_3\text{O}^+$ .

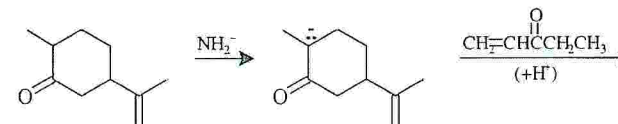
(u), (v), and (w) Acetic acid and heat to dehydrate the tertiary alcohol; followed by acetic anhydride to acetylate the secondary alcohol; followed by  $\text{H}_2$ , Pt to hydrogenate the double bond.

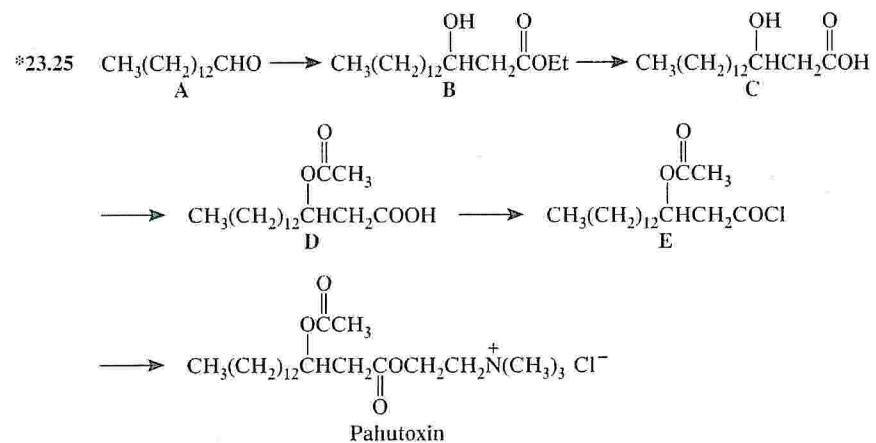
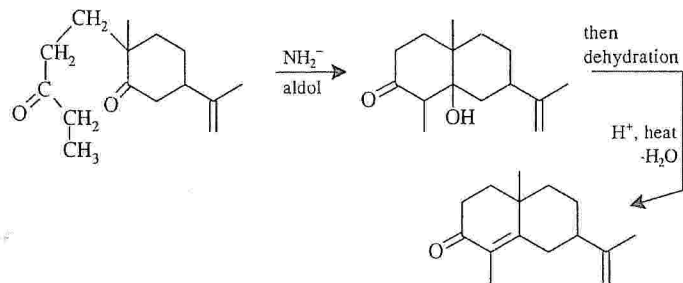


23.24 First: an elimination takes place,

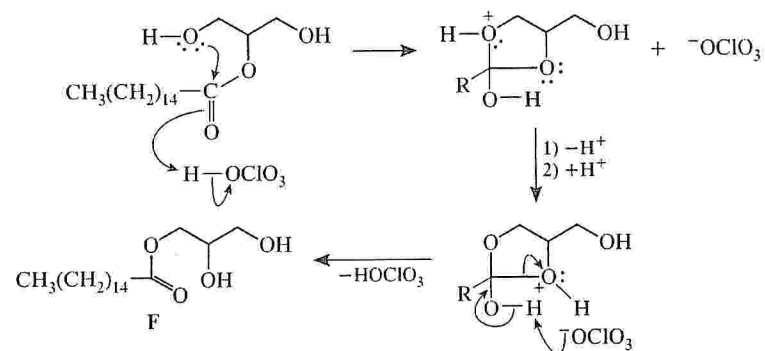


Then a conjugate addition occurs, followed by an aldol addition:



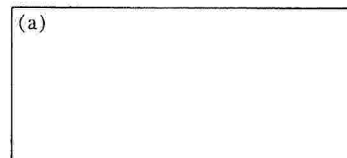


\*23.26 The reaction is an intramolecular transesterification.

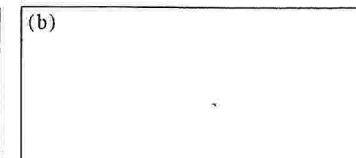


## QUIZ

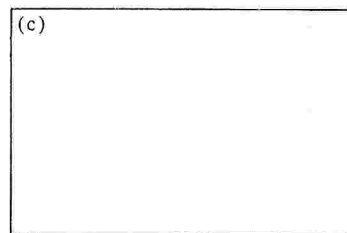
23.1 Write an appropriate formula in each box.



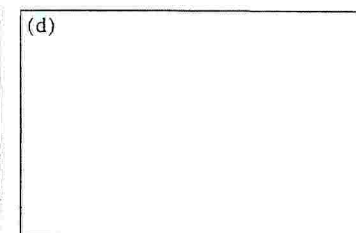
A naturally occurring fatty acid



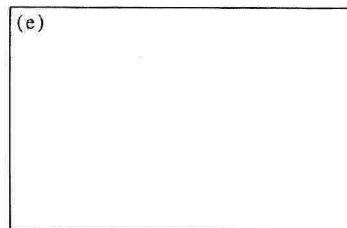
A soap



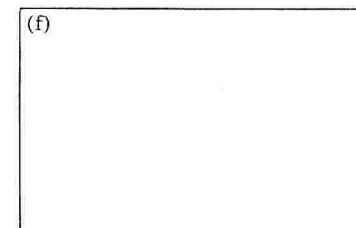
A solid fat



An oil



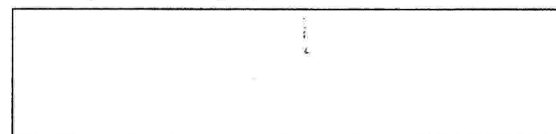
A synthetic detergent



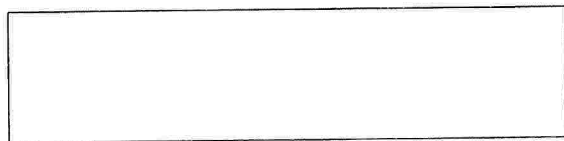
5 $\alpha$ -Estran-17-one

23.2 Give a reagent that would distinguish between each of the following:

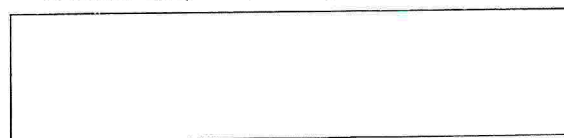
(a) Pregnane and 20-pregnanone



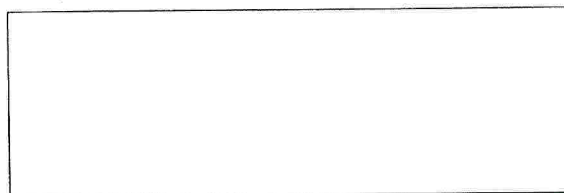
(b) Stearic acid and oleic acid



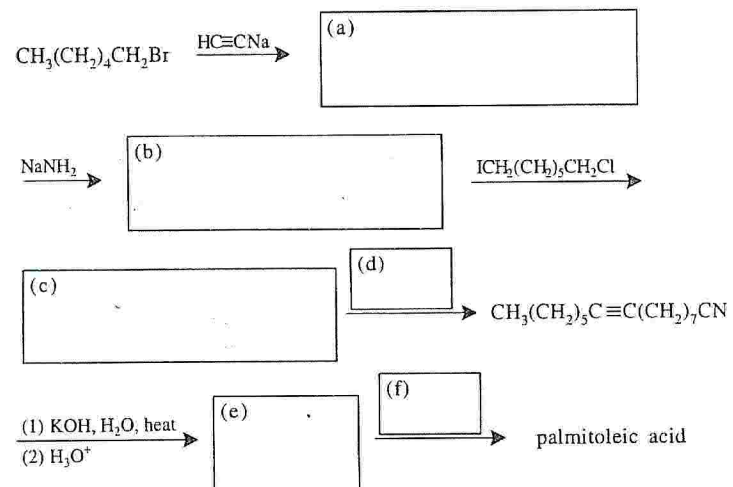
(c) 17 $\alpha$ -Ethinyl-1,3,5(10)-estratriene-3,17 $\beta$ -diol (ethynylestradiol) and 1,3,5(10)-estratriene-3,17 $\beta$ -diol (estradiol)



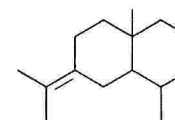
23.3 What product would be obtained by catalytic hydrogenation of 4-androstene?



23.4 Supply the missing compounds:

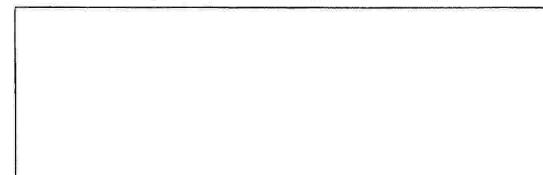


23.5 The following compound is a:



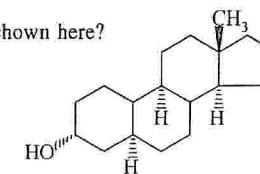
- (a) Monoterpene      (b) Sesquiterpene      (c) Diterpene  
(d) Triterpene      (e) Tetraterpene

23.6 Mark off the isoprene units in the previous compound.



23.7 Which is a systematic name for the steroid shown here?

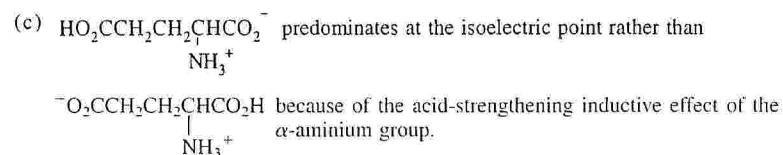
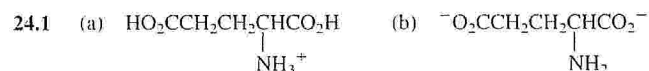
- (a) 5 $\alpha$ -Androstan-3 $\alpha$ -ol  
(b) 5 $\beta$ -Androstan-3 $\beta$ -ol  
(c) 5 $\alpha$ -Pregnan-3 $\alpha$ -ol  
(d) 5 $\beta$ -Pregnan-3 $\beta$ -ol  
(e) 5 $\alpha$ -Estran-3 $\alpha$ -ol





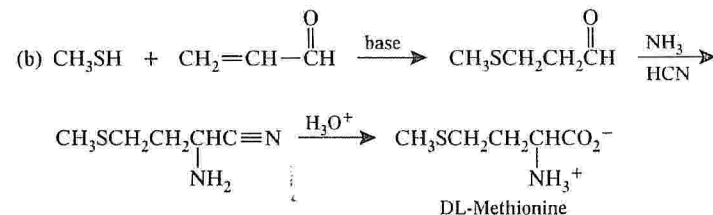
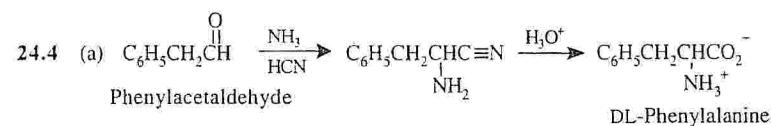
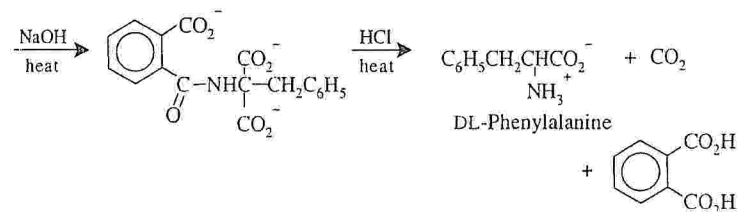
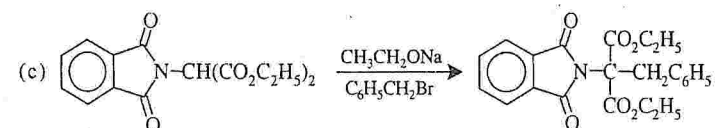
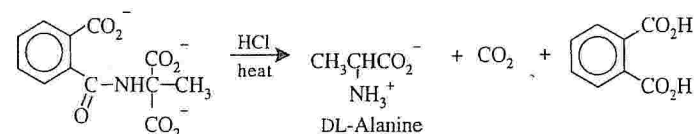
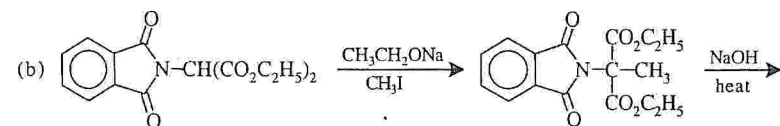
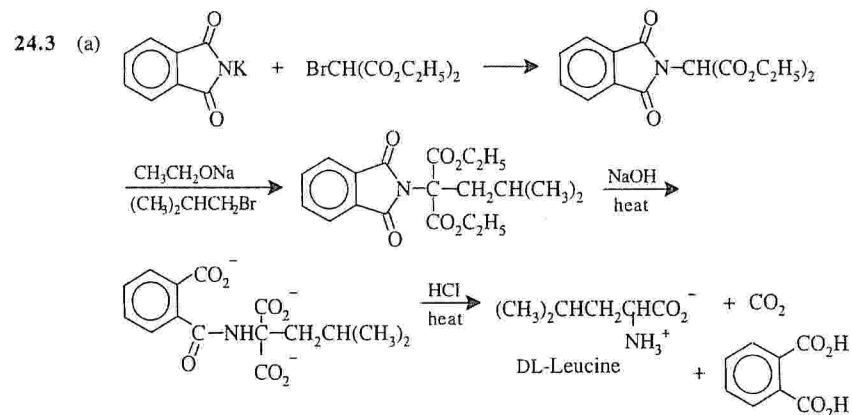
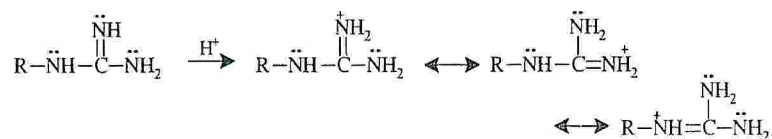
# 24 AMINO ACIDS AND PROTEINS

## SOLUTIONS TO PROBLEMS

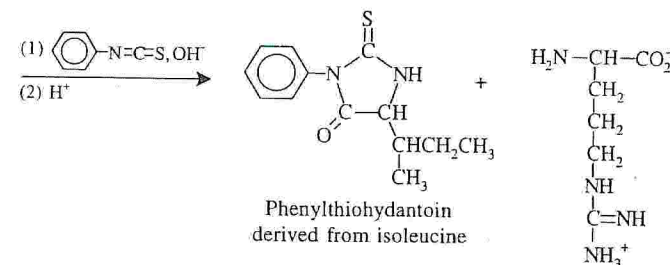
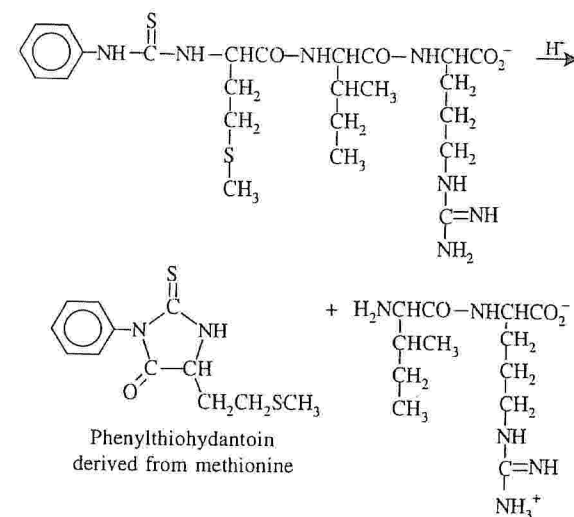
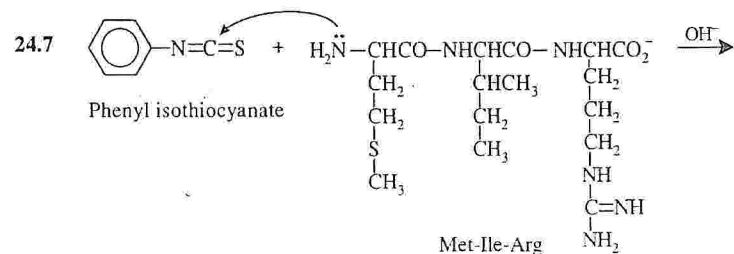
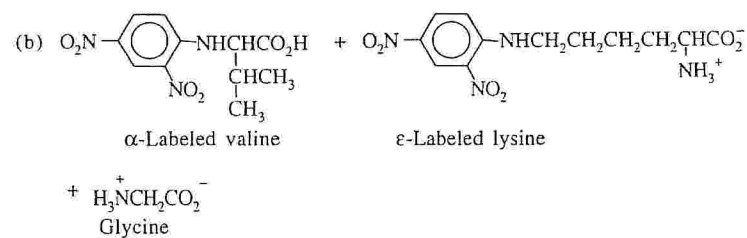
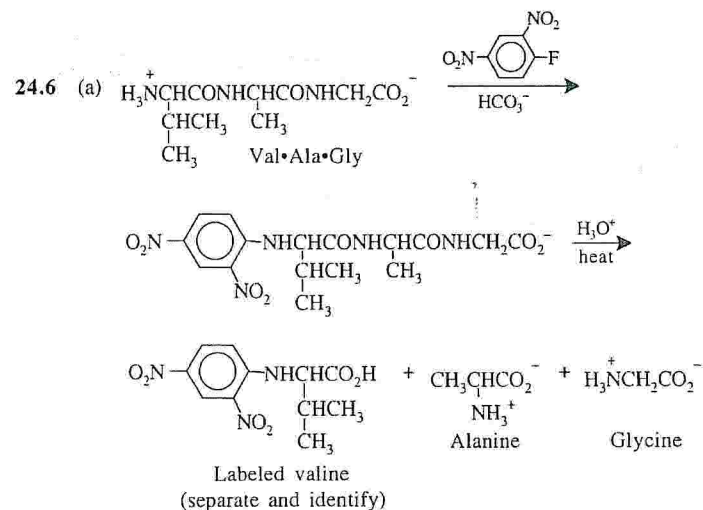


(d) Since glutamic acid is a dicarboxylic acid, acid must be added (i.e., the pH must be made lower) to suppress the ionization of the second carboxyl group and thus achieve the isoelectric point. Glutamine, with only one carboxyl group, is similar to glycine or phenylalanine and has its isoelectric point at a higher pH.

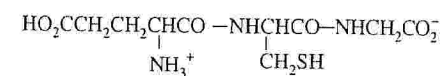
24.2 The conjugate acid is highly stabilized by resonance.



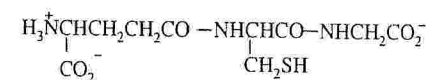
24.5 Because of the presence of an electron-withdrawing 2,4-dinitrophenyl group, the labeled amino acid is relatively nonbasic and is, therefore, insoluble in dilute aqueous acid. The other amino acids (those that are not labeled) dissolve in dilute aqueous acid.



- 24.8 (a) Two structures are possible with the sequence Glu•Cys•Gly. Glutamic acid may be linked to cysteine through its  $\alpha$ -carboxyl group,

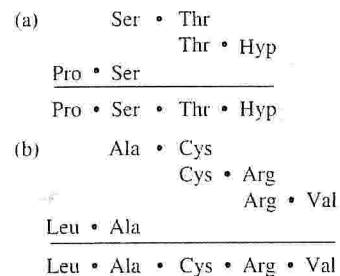


or through its  $\gamma$ -carboxyl group,

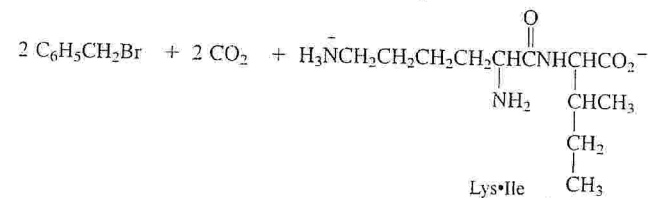
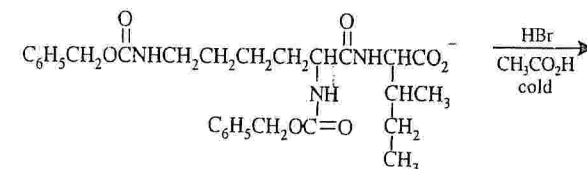
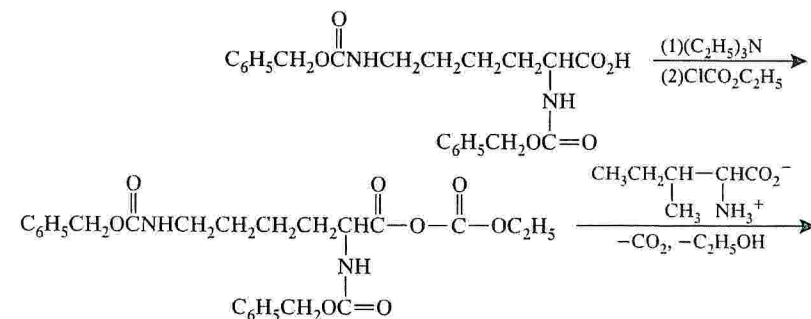
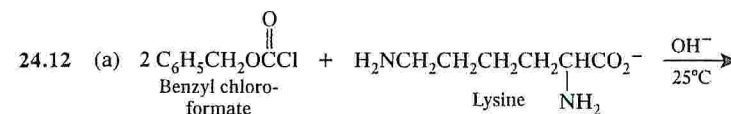
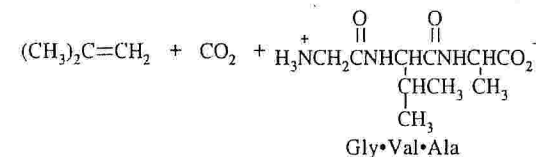
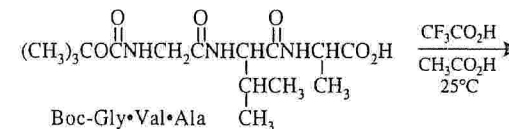
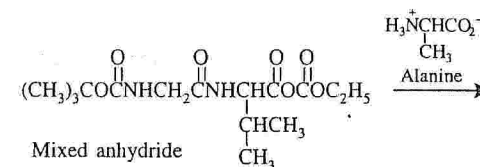
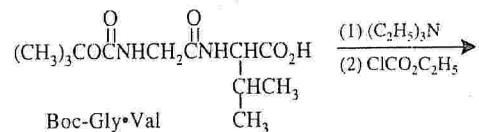
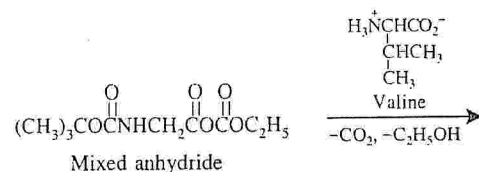
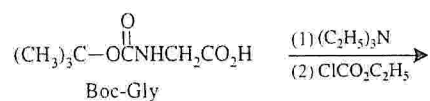
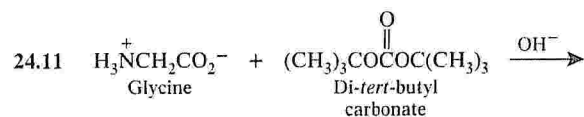
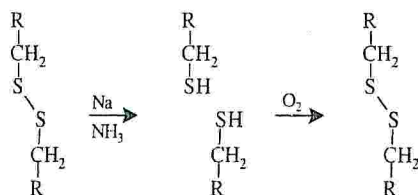


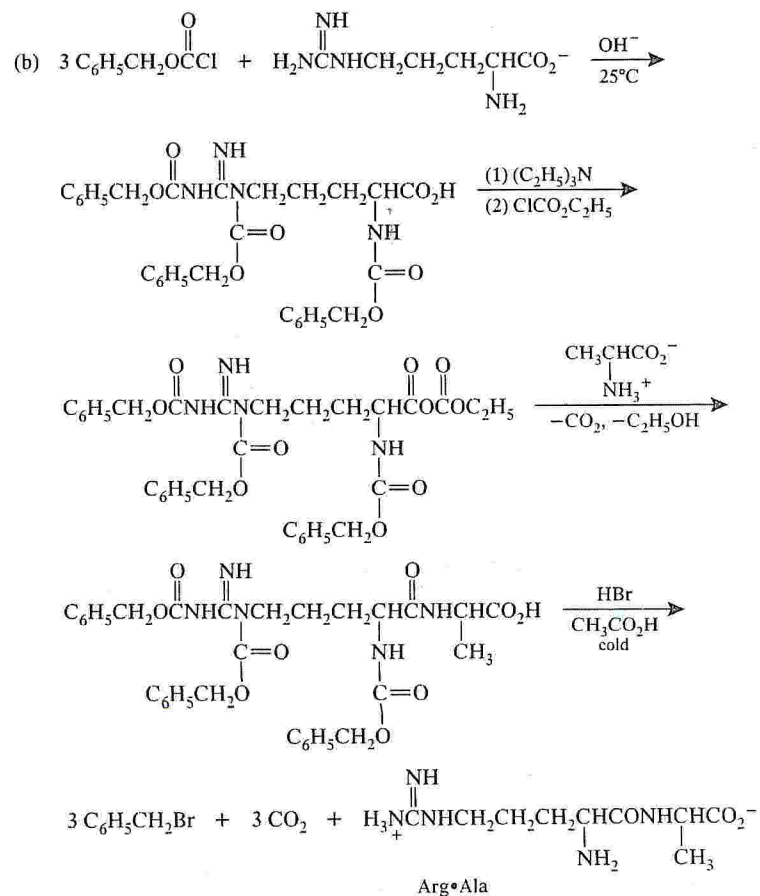
- (b) This result shows that the second structure is correct, that in glutathione the  $\gamma$ -carboxyl group is linked to cysteine.

24.9 We look for points of overlap to determine the amino acid sequence in each case.



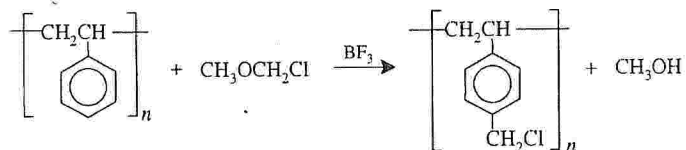
24.10 Sodium in liquid ammonia brings about reductive cleavage of the disulfide linkage of oxytocin to two thiol groups; then air oxidizes the two thiol groups back to a disulfide linkage:



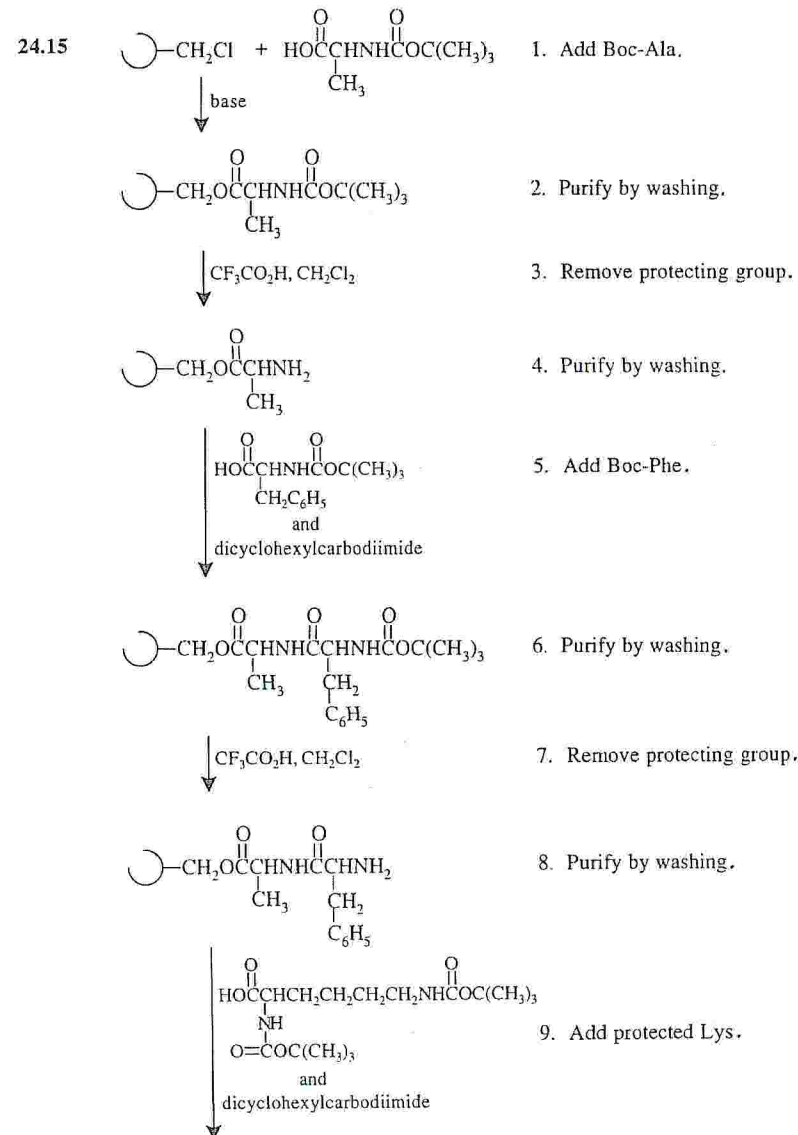


24.13 The weakness of the benzyl-oxygen bond allows these groups to be removed by catalytic hydrogenolysis.

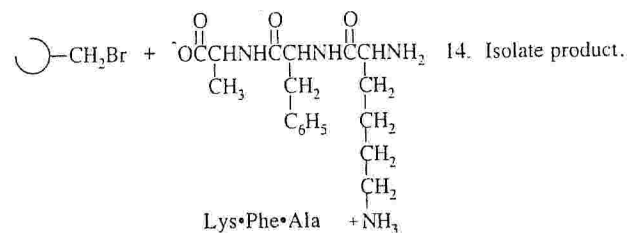
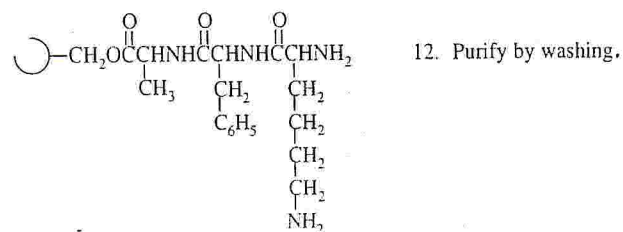
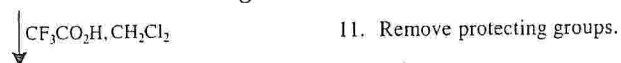
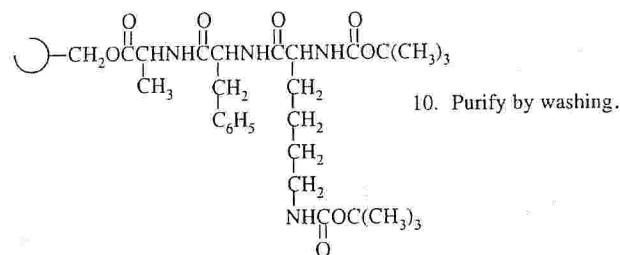
24.14 (a) An electrophilic substitution reaction:



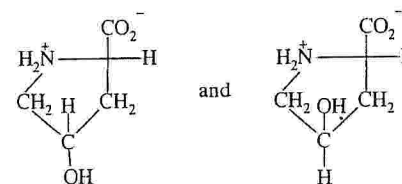
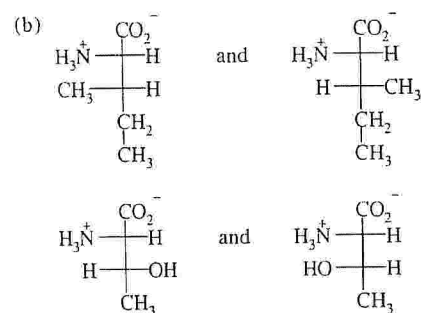
(b) The linkage between the resin and the polypeptide is a benzylic ester. It is cleaved by HBr in  $\text{CF}_3\text{CO}_2\text{H}$  at room temperature because the carbocation that is formed initially is the relatively stable, benzylic cation.







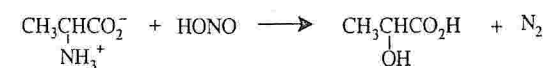
24.16 (a) Isoleucine, threonine, hydroxyproline, and cystine.



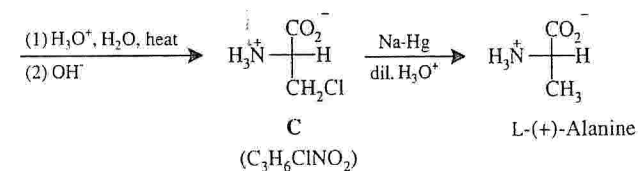
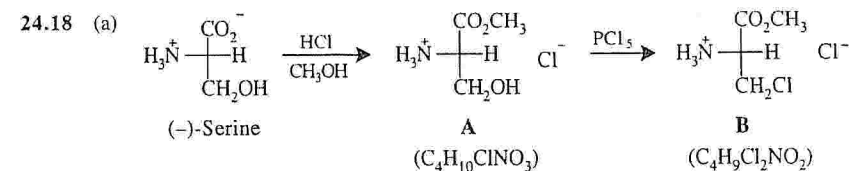
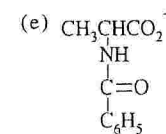
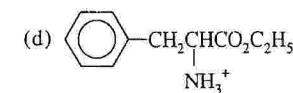
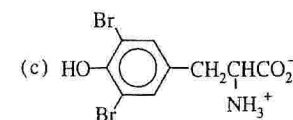
(With cystine, both stereocenters are  $\alpha$ -carbon atoms; thus, according to the problem, both must have the L-configuration, and no isomers of this type can be written.)

(c) Diastereomers

24.17 (a) Alanine

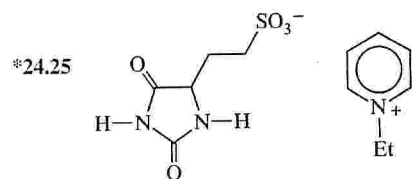


(b) Proline and hydroxyproline. All of the other amino acids have at least one primary amino group.







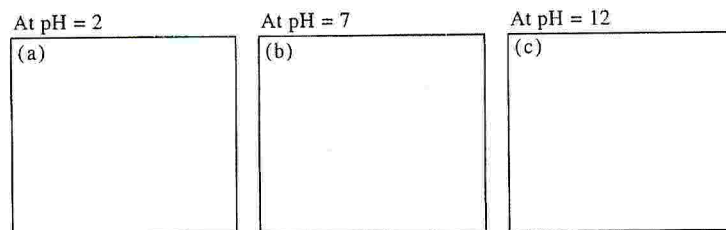


(By pyridine displacement of the sulfonyloxy group of the initially formed ethyl ester.)

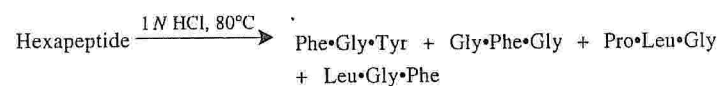
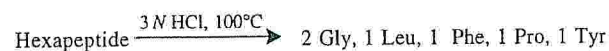
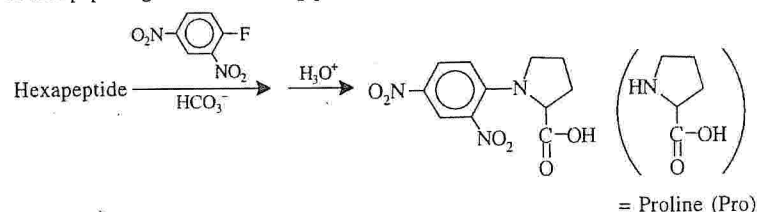
- \*24.26 (a) A large difference in the solubilities of the (*S,S*) and (*S,R*) diastereomers.  
 (b) Le Chatelier's Principle, which says that an equilibrium system will try to produce more of any species that is removed (here by crystallization).  
 (c) Hydrogenolysis of benzyl groups, in both instances (one is preceded by simple hydrogenation of the ketone carbonyl group).

## QUIZ

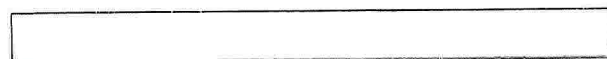
- 24.1 Write the structural formula of the principal ionic species present in aqueous solutions at pH 2, 7, and 12 of isoleucine (2-amino-3-methylpentanoic acid).



- 24.2 A hexapeptide gave the following products:



The structure of the hexapeptide (using abbreviations such as Gly•Leu•etc.) is

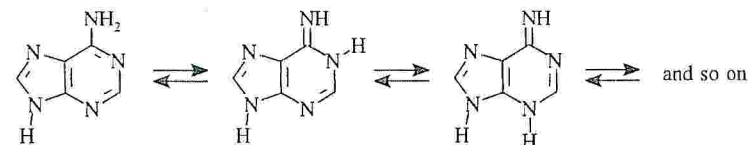


# 25

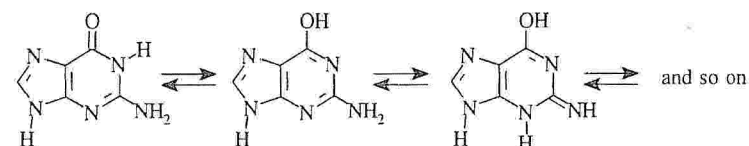
## NUCLEIC ACIDS AND PROTEIN SYNTHESIS

## SOLUTIONS TO PROBLEMS

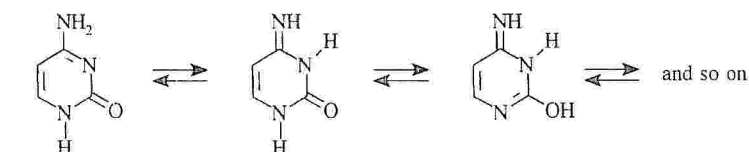
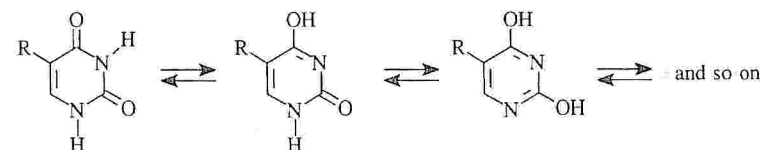
## 25.1 Adenine:



## Guanine:

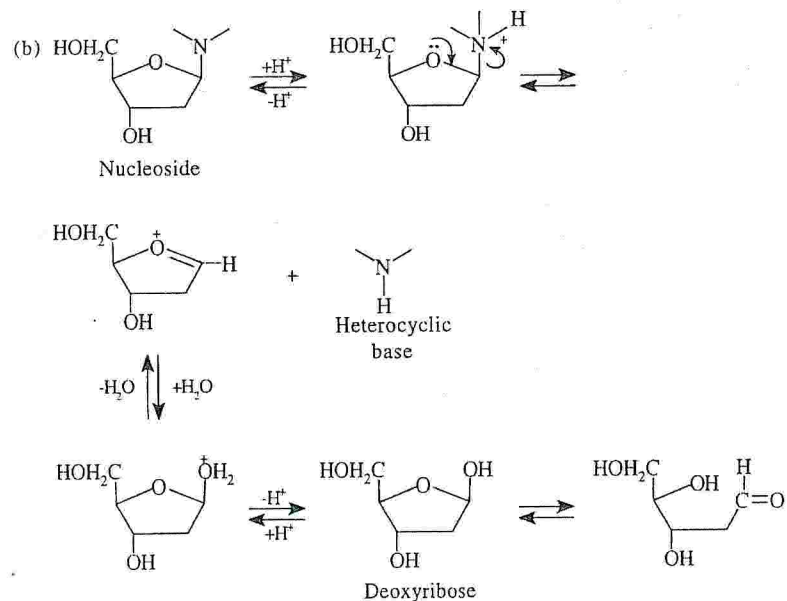


## Cytosine:

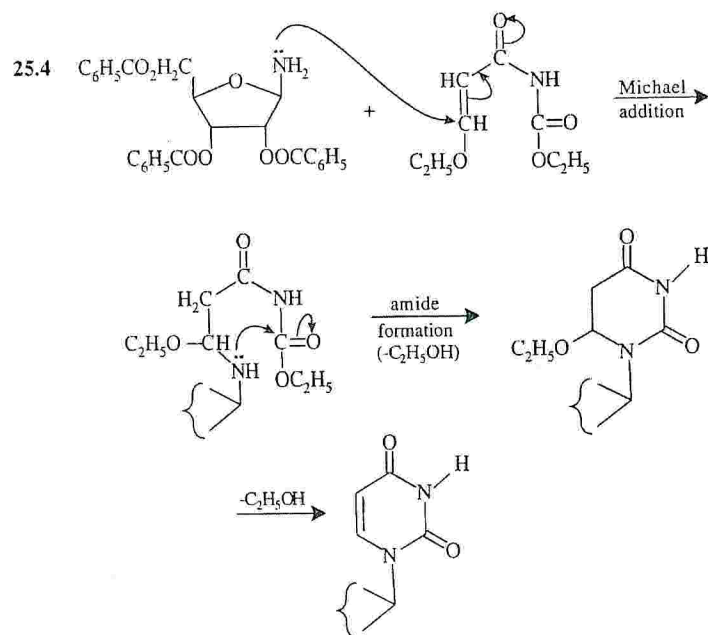
Thymine (R=CH<sub>3</sub>) or Uracil (R=H):

- 25.2 (a) The nucleosides have an *N*-glycosidic linkage that (like an *O*-glycosidic linkage) is rapidly hydrolyzed by aqueous acid but is one that is stable in aqueous base.



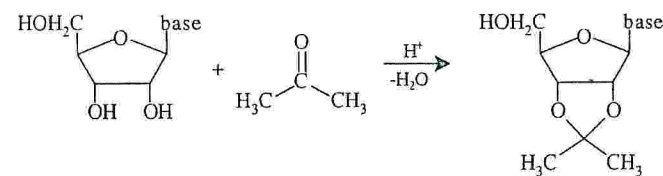


25.3 The reaction appears to take place through an  $S_N2$  mechanism. Attack occurs preferentially at the primary 5'-carbon atom rather than at the secondary 3'-carbon atom.



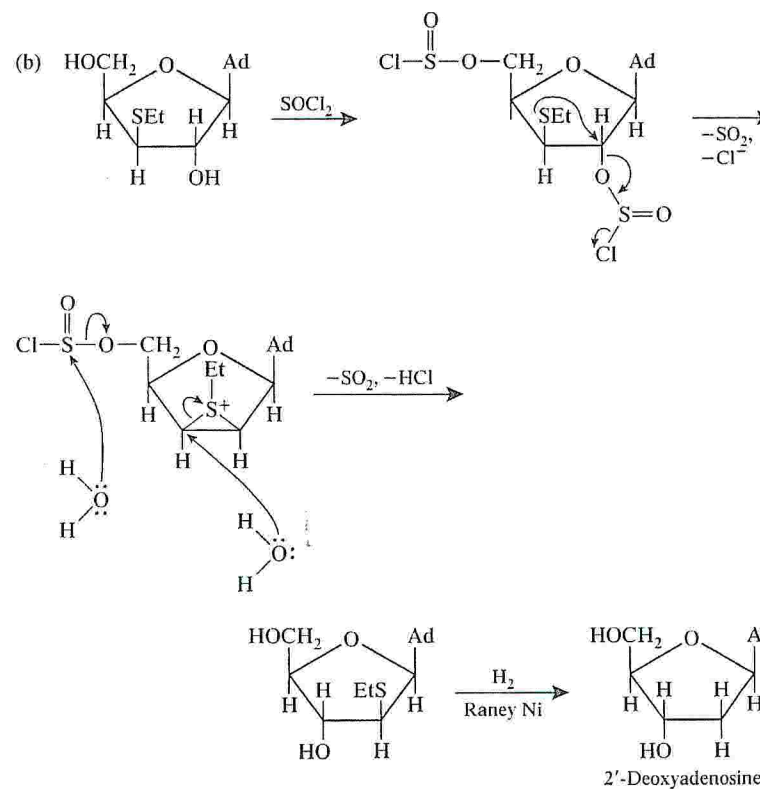
25.5 (a) The isopropylidene group is part of a cyclic acetal and is thus susceptible to hydrolysis by mild acid.

(b) It can be installed by treating the nucleoside with acetone and a trace of acid and by simultaneously removing the water that is produced.



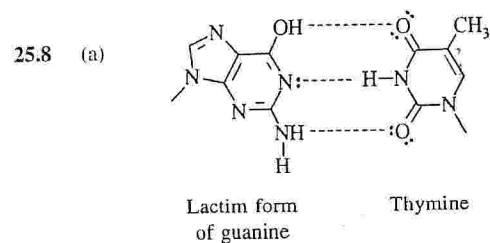
25.6 (a) Cordycepin is

(3'-Deoxyadenosine)



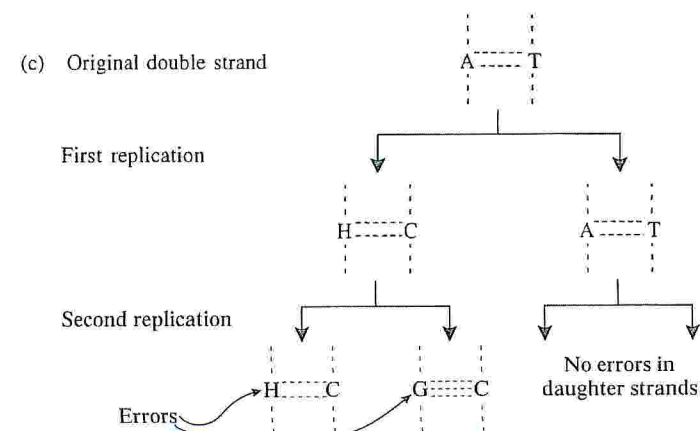
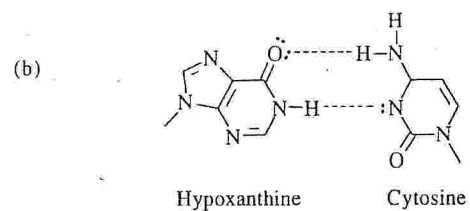
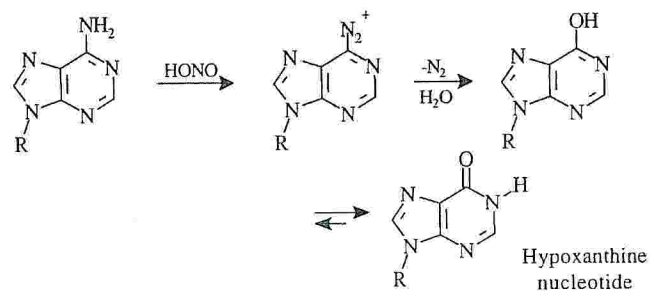
25.7 (a)  $6 \times 10^9 \text{ base pairs} \times \frac{34 \text{ \AA}}{10 \text{ base pairs}} \times \frac{10^{-10} \text{ m}}{\text{\AA}} \approx 2 \text{ m}$

(b)  $6 \times 10^{-12} \frac{\text{g}}{\text{ovum}} \times 3 \times 10^9 \text{ ova} = 1.8 \times 10^{-2} \text{ g}$

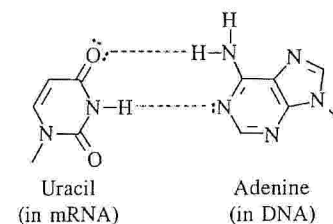


(b) Thymine would pair with adenine and thus adenine would be introduced into the complementary strand where guanine should occur.

25.9 (a) A diazonium salt and a heterocyclic analog of a phenol.



25.10



|           |     |     |     |     |     |             |
|-----------|-----|-----|-----|-----|-----|-------------|
| 25.11 (a) | UGG | GGG | UUU | UAC | AGC | mRNA        |
| (b)       | Tyr | Gly | Phe | Tyr | Ser | Amino acids |
| (c)       | ACC | CCC | AAA | AUG | UCG | Anticodons  |

|           |     |     |     |     |     |             |
|-----------|-----|-----|-----|-----|-----|-------------|
| 25.12 (a) | Arg | Ile | Cys | Tyr | Val | Amino acids |
| (b)       | AGA | AUA | UGC | UGG | GUA | mRNA        |
| (c)       | TCT | TAT | ACG | ACC | CAT | DNA         |
|           | UCU | UAU | ACG | ACC | CAU | Anticodons  |

25.13 A change from C-T-T to C-A-T or a change from C-T-C to C-A-C.

# A

## APPENDIX

### Empirical and Molecular Formulas

In Section 1.2B, we discussed briefly the pioneering work of Berzelius, Dumas, Liebig, and Cannizzaro in devising methods for determining the formulas of organic compounds. Although the experimental procedures for these analyses have been refined, the basic methods for determining the elemental composition of an organic compound today are not substantially different from those used in the nineteenth century. A carefully weighed quantity of the compound to be analyzed is oxidized completely to carbon dioxide and water. The weights of carbon dioxide and water are carefully measured and used to find the percentages of carbon and hydrogen in the compound. The percentage of nitrogen is usually determined by measuring the volume of nitrogen ( $N_2$ ) produced in a separate procedure.

Special techniques for determining the percentage composition of other elements typically found in organic compounds have also been developed, but the direct determination of the percentage of oxygen is difficult. However, if the percentage composition of all the other elements is known, then the percentage of oxygen can be determined by difference. The following examples will illustrate how these calculations can be carried out.

#### EXAMPLE A

A new organic compound is found to have the following elemental analysis.

|          |        |
|----------|--------|
| Carbon   | 67.95% |
| Hydrogen | 5.69   |
| Nitrogen | 26.20  |
| Total:   | 99.84% |

Since the total of these percentages is very close to 100% (within experimental error), we can assume that no other element is present. For the purpose of our calculation it is convenient to assume that we have a 100-g sample. If we did, it would contain the following:

67.95 g of carbon  
5.69 g of hydrogen  
26.20 g of nitrogen

In other words, we use percentages *by weight* to give us the ratios *by weight* of the elements in the substance. To write a formula for the substance, however, we need *ratios by moles*.

We now divide each of these weight-ratio numbers by the atomic weight of the particular element and obtain the number of moles of each element, respectively, in 100 g of the compound. This operation gives us the ratios *by moles* of the elements in the substance:

$$\begin{aligned} \text{C} \quad & \frac{67.95 \text{ g}}{12.01 \text{ g mol}^{-1}} = 5.66 \text{ mol} \\ \text{H} \quad & \frac{5.69 \text{ g}}{1.008 \text{ g mol}^{-1}} = 5.64 \text{ mol} \\ \text{N} \quad & \frac{26.20 \text{ g}}{14.01 \text{ g mol}^{-1}} = 1.87 \text{ mol} \end{aligned}$$

One possible formula for the compound, therefore, is  $C_{5.66}H_{5.64}N_{1.87}$ .

By convention, however, we use *whole* numbers in formulas. Therefore, we convert these fractional numbers of moles to whole numbers by dividing each by 1.87, the smallest number.

$$\begin{aligned} \text{C} \quad & \frac{5.66}{1.87} = 3.03 \text{ which is } \sim 3 \\ \text{H} \quad & \frac{5.64}{1.87} = 3.02 \text{ which is } \sim 3 \\ \text{N} \quad & \frac{1.87}{1.87} = 1.00 \end{aligned}$$

Thus, within experimental error, the ratios by moles are 3 C to 3 H to 1 N, and  $C_3H_3N$  is the *empirical formula*. By empirical formula, we mean the formula in which the subscripts are the smallest integers that give the ratio of atoms in the compound. In contrast, a *molecular formula* discloses the complete composition of one molecule. The molecular formula of this particular compound could be  $C_3H_3N$  or some whole number multiple of  $C_3H_3N$ ; that is,  $C_6H_6N_2$ ,  $C_9H_9N_3$ ,  $C_{12}H_{12}N_4$ , and so on. If, in a separate determination, we find that the molecular weight of the compound is  $108 \pm 3$ , we can be certain that the *molecular formula* of the compound is  $C_6H_6N_2$ .

| FORMULA | MOLECULAR WEIGHT |
|---------|------------------|
|---------|------------------|

|                   |                                                 |
|-------------------|-------------------------------------------------|
| $C_3H_3N$         | 53.06                                           |
| $C_6H_6N_2$       | 106.13 (which is within the range $108 \pm 3$ ) |
| $C_9H_9N_3$       | 159.19                                          |
| $C_{12}H_{12}N_4$ | 212.26                                          |

The most accurate method for determining molecular weights is by mass spectrometry. A variety of other methods based on freezing point depression, boiling point elevation, osmotic pressure, and vapor density can also be used to determine molecular weights.

## EXAMPLE B

Histidine, an amino acid isolated from protein, has the following elemental analysis:

|            |                              |
|------------|------------------------------|
| Carbon     | 46.38%                       |
| Hydrogen   | 5.90                         |
| Nitrogen   | 27.01                        |
| Total:     | <u>79.29</u>                 |
| Difference | 20.71 (assumed to be oxygen) |
|            | <u>100.00%</u>               |

Since no elements, other than carbon, hydrogen, and nitrogen, are found to be present in histidine, the difference is assumed to be oxygen. Again, we assume a 100-g sample and divide the weight of each element by its gram-atomic weight. This gives us the ratio of moles (A).

|   | (A)                          | (B)                        | (C)                                     |
|---|------------------------------|----------------------------|-----------------------------------------|
| C | $\frac{46.38}{12.01} = 3.86$ | $\frac{3.86}{1.29} = 2.99$ | $\times 2 = 5.98 \sim 6$ carbon atoms   |
| H | $\frac{5.90}{1.008} = 5.85$  | $\frac{5.85}{1.29} = 4.53$ | $\times 2 = 9.06 \sim 9$ hydrogen atoms |
| N | $\frac{27.01}{14.01} = 1.93$ | $\frac{1.93}{1.29} = 1.50$ | $\times 2 = 3.00 = 3$ nitrogen atoms    |
| O | $\frac{20.71}{16.00} = 1.29$ | $\frac{1.29}{1.29} = 1.00$ | $\times 2 = 2.00 = 2$ oxygen atoms      |

Dividing each of the moles (A) by the smallest of them does not give a set of numbers (B) that is close to a set of whole numbers. Multiplying each of the numbers in column (B) by 2 does, however, as seen in column (C). The empirical formula of histidine is, therefore,  $C_6H_9N_3O_2$ .

In a separate determination, the molecular weight of histidine was found to be  $158 \pm 5$ . The empirical formula weight of  $C_6H_9N_3O_2$  (155.15) is within this range; thus, the molecular formula for histidine is the same as the empirical formula.

## PROBLEMS

A.1 What is the empirical formula of each of the following compounds?

- |                          |                                 |
|--------------------------|---------------------------------|
| (a) Hydrazine, $N_2H_4$  | (d) Nicotine, $C_{10}H_{14}N_2$ |
| (b) Benzene, $C_6H_6$    | (e) Cyclodecane, $C_{10}H_{20}$ |
| (c) Dioxane, $C_4H_8O_2$ | (f) Acetylene, $C_2H_2$         |

A.2 The empirical formulas and molecular weights of several compounds are given next. In each case, calculate the molecular formula for the compound.

| EMPIRICAL FORMULA | MOLECULAR WEIGHT |
|-------------------|------------------|
| (a) $CH_2O$       | $179 \pm 5$      |
| (b) $CHN$         | $80 \pm 5$       |
| (c) $CCl_2$       | $410 \pm 10$     |

A.3 The widely used antibiotic, penicillin G, gave the following elemental analysis: C, 57.45%; H, 5.40%; N, 8.45%; S, 9.61%. The molecular weight of penicillin G is  $330 \pm 10$ . Assume that no other elements except oxygen are present and calculate the empirical and molecular formulas for penicillin G.

## ADDITIONAL PROBLEMS

A.4 Calculate the percentage composition of each of the following compounds.

- (a)  $C_6H_{12}O_6$   
 (b)  $CH_3CH_2NO_2$   
 (c)  $CH_3CH_2CBr_3$

A.5 An organometallic compound called *ferrocene* contains 30.02% iron. What is the minimum molecular weight of ferrocene?

A.6 A gaseous compound gave the following analysis: C, 40.04%; H, 6.69%. At standard temperature and pressure, 1.00 g of the gas occupied a volume of 746 mL. What is the molecular formula of the compound?

A.7 A gaseous hydrocarbon has a density of  $1.251 \text{ g L}^{-1}$  at standard temperature and pressure. When subjected to complete combustion, a 1.000-L sample of the hydrocarbon gave 3.926 g of carbon dioxide and 1.608 g of water. What is the molecular formula for the hydrocarbon?

A.8 Nicotinamide, a vitamin that prevents the occurrence of pellagra, gave the following analysis: C, 59.10%; H, 4.92%; N, 22.91%. The molecular weight of nicotinamide was shown in a separate determination to be  $120 \pm 5$ . What is the molecular formula for nicotinamide?

A.9 The antibiotic chloramphenicol gave the following analysis: C, 40.88%; H, 3.74%; Cl, 21.95%; N, 8.67%. The molecular weight was found to be  $300 \pm 30$ . What is the molecular formula for chloramphenicol?



## SOLUTIONS TO PROBLEMS OF APPENDIX A

A.1 (a)  $\text{NH}_2$  (b)  $\text{CH}$  (c)  $\text{C}_2\text{H}_4\text{O}$  (d)  $\text{C}_5\text{H}_7\text{N}$  (e)  $\text{CH}_2$  (f)  $\text{CH}$ 

| EMPIRICAL<br>FORMULA      | EMPIRICAL<br>FORMULA<br>WEIGHT | $\left( \frac{\text{MOLECULAR WEIGHT}}{\text{EMP. FORM. WT.}} \right)$ | MOLECULAR<br>FORMULA                |
|---------------------------|--------------------------------|------------------------------------------------------------------------|-------------------------------------|
| (a) $\text{CH}_2\text{O}$ | 30                             | $\frac{179}{30} \approx 6$                                             | $\text{C}_6\text{H}_{12}\text{O}_6$ |
| (b) $\text{CHN}$          | 27                             | $\frac{80}{27} \approx 3$                                              | $\text{C}_3\text{H}_3\text{N}_3$    |
| (c) $\text{CCl}_2$        | 83                             | $\frac{410}{83} \approx 5$                                             | $\text{C}_5\text{Cl}_{10}$          |

A.3 If we assume that we have a 100-g sample, the amounts of the elements are

|    | WEIGHT                 | Moles (A)                    | B                                |
|----|------------------------|------------------------------|----------------------------------|
| C  | 57.45                  | $\frac{57.45}{12.01} = 4.78$ | $\frac{4.78}{0.300} = 15.9 = 16$ |
| H  | 5.40                   | $\frac{5.40}{1.008} = 5.36$  | $\frac{5.36}{0.300} = 17.9 = 18$ |
| N  | 8.45                   | $\frac{8.45}{14.01} = 0.603$ | $\frac{0.603}{0.300} = 2.01 = 2$ |
| S  | 9.61                   | $\frac{9.61}{32.06} = 0.300$ | $\frac{0.300}{0.300} = 1.00 = 1$ |
| O* | $\frac{19.09}{100.00}$ | $\frac{19.09}{16.00} = 1.19$ | $\frac{1.19}{0.300} = 3.97 = 4$  |

(\* by difference from 100)

The empirical formula is thus  $\text{C}_{16}\text{H}_{18}\text{N}_2\text{SO}_4$ . The empirical formula weight (334.4) is within the range given for the molecular weight ( $330 \pm 10$ ). Thus, the molecular formula for penicillin G is the same as the empirical formula.

A.4 (a) To calculate the percentage composition from the molecular formula, first determine the weight of each element in 1 mol of the compound. For  $\text{C}_6\text{H}_{12}\text{O}_6$ ,

$$\begin{aligned} \text{C}_6 &= 6 \times 12.01 = 72.06 & \frac{72.06}{180.2} &= 0.400 = 40.0\% \\ \text{H}_{12} &= 12 \times 1.008 = 12.10 & \frac{12.10}{180.2} &= 0.0671 = 6.7\% \\ \text{O}_6 &= 6 \times 16.00 = 96.00 & \frac{96.00}{180.2} &= 0.533 = 53.3\% \end{aligned}$$

(MW = molecular weight)

Then determine the percentage of each element using the formula

$$\text{Percentage of A} = \frac{\text{Weight of A}}{\text{Molecular Weight}} \times 100$$

$$\begin{aligned} \text{(b) } \text{C}_2 &= 2 \times 12.01 = 24.02 & \frac{24.02}{75.07} &= 0.320 = 32.0\% \\ \text{H}_3 &= 3 \times 1.008 = 3.024 & \frac{3.024}{75.07} &= 0.0403 = 4.03\% \\ \text{N} &= 1 \times 14.01 = 14.01 & \frac{14.01}{75.07} &= 0.187 = 18.7\% \\ \text{O}_2 &= 2 \times 16.00 = 32.00 & \frac{32.00}{75.07} &= 0.426 = 42.6\% \end{aligned}$$

$$\text{Total} = 75.07$$

$$\begin{aligned} \text{(c) } \text{C}_3 &= 3 \times 12.01 = 36.03 & \frac{36.03}{280.77} &= 0.128 = 12.8\% \\ \text{H}_3 &= 3 \times 1.008 = 3.024 & \frac{3.024}{280.77} &= 0.0108 = 1.08\% \\ \text{Br}_3 &= 3 \times 79.90 = 239.70 & \frac{239.70}{280.77} &= 0.854 = 85.4\% \end{aligned}$$

$$\text{Total} = 280.77$$

A.5 If the compound contains iron, each molecule must contain at least one atom of iron, and 1 mol of the compound must contain at least 55.85 g of iron. Therefore,

$$\begin{aligned} \text{MW of ferrocene} &= 55.85 \frac{\text{g of Fe}}{\text{mol}} \times \frac{1.000 \text{ g}}{0.3002 \text{ g of Fe}} \\ &= 186.0 \frac{\text{g}}{\text{mol}} \end{aligned}$$

A.6 First, we must determine the empirical formula. Assuming that the difference between the percentages given and 100% is due to oxygen, we calculate:

$$\begin{aligned} \text{C} &= 40.04 & \frac{40.04}{12.01} &= 3.33 & \frac{3.33}{3.33} &= 1 \\ \text{H} &= 6.69 & \frac{6.69}{1.008} &= 6.64 & \frac{6.64}{3.33} &\approx 2 \\ \text{O} &= \frac{53.27}{100.00} & \frac{53.27}{16.00} &= 3.33 & \frac{3.33}{3.33} &= 1 \end{aligned}$$

The empirical formula is thus  $\text{CH}_2\text{O}$ .

To determine the molecular formula, we must first determine the molecular weight. At standard temperature and pressure, the volume of 1 mol of an ideal gas is 22.4 L. Assuming ideal behavior,

$$\frac{1.00 \text{ g}}{0.746 \text{ L}} = \frac{\text{MW}}{22.4 \text{ L}} \text{ where MW = molecular weight}$$

$$\text{MW} = \frac{(1.00)(22.4)}{0.746} = 30.0 \text{ g}$$

The empirical formula weight (30.0) equals the molecular weight; thus, the molecular formula is the same as the empirical formula.

**A.7** As in Problem A.6, the molecular weight is found by the equation

$$\frac{1.251 \text{ g}}{1.00 \text{ L}} = \frac{\text{MW}}{22.4 \text{ L}}$$

$$\text{MW} = (1.251)(22.4)$$

$$\text{MW} = 28.02$$

To determine the empirical formula, we must determine the amount of carbon in 3.926 g of carbon dioxide, and the amount of hydrogen in 1.608 g of water.

$$\text{C} \left( 3.926 \text{ g } \text{CO}_2 \right) \left( \frac{12.01 \text{ g C}}{44.01 \text{ g CO}_2} \right) = 1.071 \text{ g carbon}$$

$$\text{H} \left( 1.608 \text{ g } \text{H}_2\text{O} \right) \left( \frac{2.016 \text{ g H}}{18.016 \text{ g H}_2\text{O}} \right) = \frac{0.180 \text{ g hydrogen}}{1.251 \text{ g sample}}$$

The weight of C and H in a 1.251-g sample is 1.251 g. Therefore, there are no other elements present.

To determine the empirical formula, we proceed as in Problem A.6 except that the sample size is 1.251 g instead of 100 g.

$$\text{C} \quad \frac{1.071}{12.01} = 0.0892 \quad \frac{0.0892}{0.0892} = 1$$

$$\text{H} \quad \frac{0.180}{1.008} = 0.179 \quad \frac{0.179}{0.0892} = 2$$

The empirical formula is thus  $\text{CH}_2$ . The empirical formula weight (14) is one-half the molecular weight. Thus, the molecular formula is  $\text{C}_2\text{H}_4$ .

**A.8** Use the procedure of Problem A.3.

$$\text{C} \quad 59.10 \quad \frac{59.10}{12.01} = 4.92 \quad \frac{4.92}{0.817} = 6.02 \approx 6$$

$$\text{H} \quad 4.92 \quad \frac{4.92}{1.008} = 4.88 \quad \frac{4.88}{0.817} = 5.97 \approx 6$$

$$\text{N} \quad 22.91 \quad \frac{22.91}{14.01} = 1.64 \quad \frac{1.64}{0.817} = 2$$

$$\text{O} \quad \frac{13.07}{100.00} \quad \frac{13.07}{16.00} = 0.817 \quad \frac{0.817}{0.817} = 1$$

The empirical formula is thus  $\text{C}_6\text{H}_6\text{N}_2\text{O}$ . The empirical formula weight is 122.13, which is equal to the molecular weight within experimental error. The molecular formula is thus the same as the empirical formula.

**A.9**

$$\text{C} \quad 40.88 \quad \frac{40.88}{12.01} = 3.40 \quad \frac{3.40}{0.619} = 5.5 \quad 5.5 \times 2 = 11$$

$$\text{H} \quad 3.74 \quad \frac{3.74}{1.008} = 3.71 \quad \frac{3.71}{0.619} = 6 \quad 6 \times 2 = 12$$

$$\text{Cl} \quad 21.95 \quad \frac{21.95}{35.45} = 0.619 \quad \frac{0.619}{0.619} = 1 \quad 1 \times 2 = 2$$

$$\text{N} \quad 8.67 \quad \frac{8.67}{14.01} = 0.619 \quad \frac{0.619}{0.619} = 1 \quad 1 \times 2 = 2$$

$$\text{O} \quad \frac{24.76}{100.00} \quad \frac{24.76}{16.00} = 1.55 \quad \frac{1.55}{0.619} = 2.5 \quad 2.5 \times 2 = 5$$

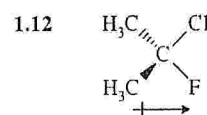
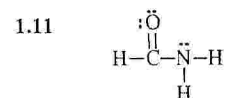
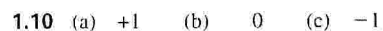
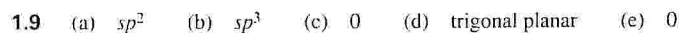
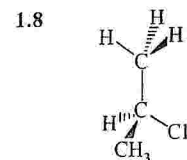
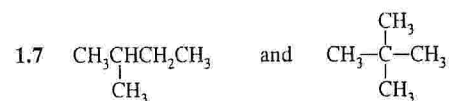
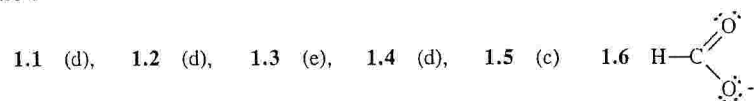
The empirical formula is thus  $\text{C}_{11}\text{H}_{12}\text{Cl}_2\text{N}_2\text{O}_5$ . The empirical formula weight (323) is equal to the molecular weight; therefore, the molecular formula is the same as the empirical formula.

# B

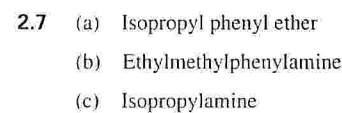
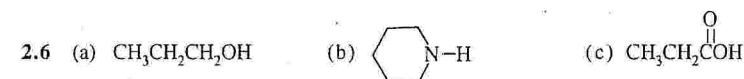
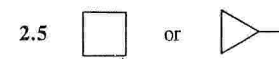
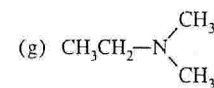
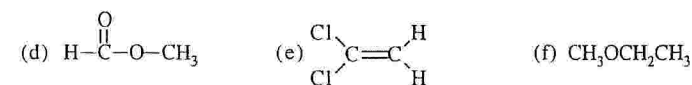
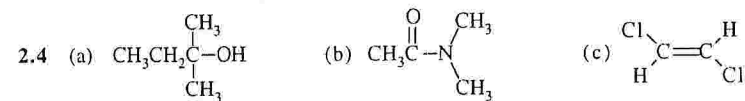
## APPENDIX

### Answers to Quizzes

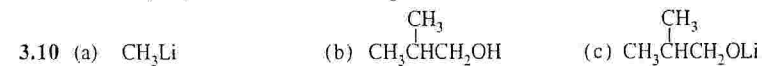
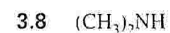
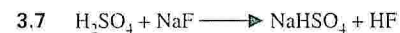
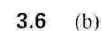
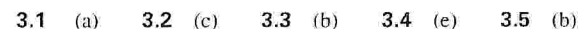
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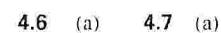
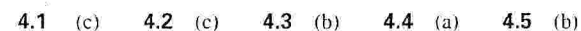
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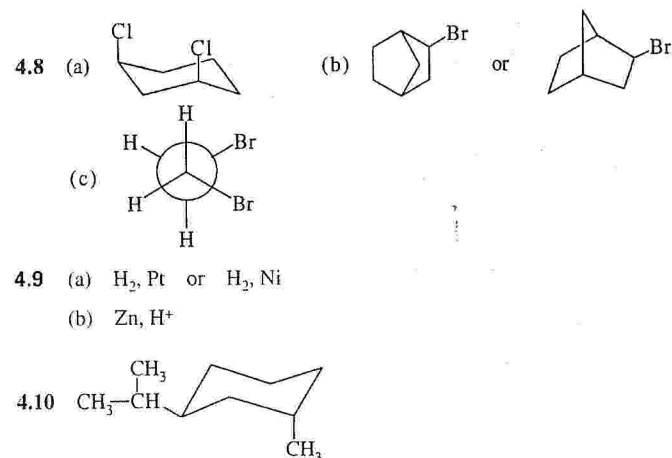


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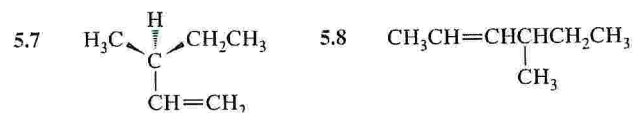
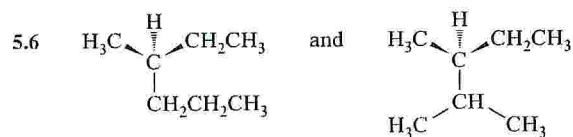
#### CHAPTER 4





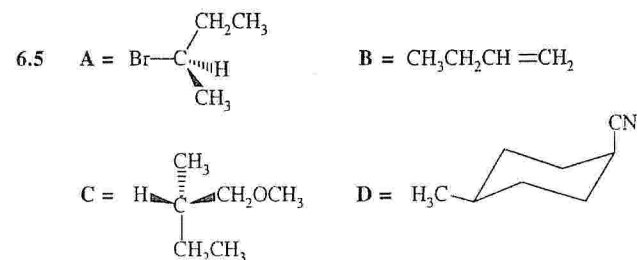
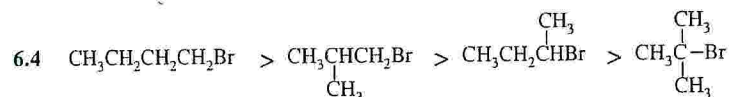
## CHAPTER 5

5.1 (a) 5.2 (b) 5.3 (b) 5.4 (e) 5.5 (b)

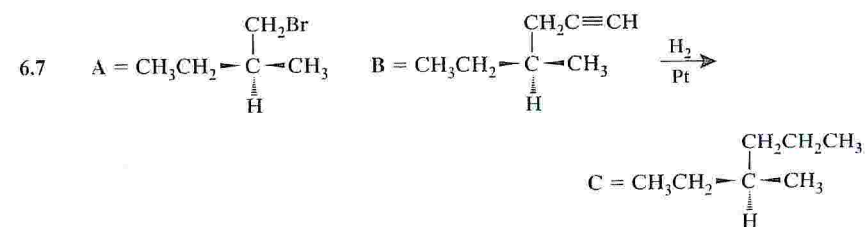


## CHAPTER 6

6.1 (b) 6.2 (b) 6.3 (a)



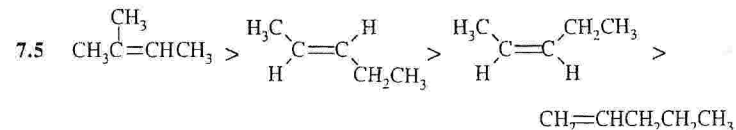
6.6 (b)



## CHAPTER 7

7.1 (c) 7.2 (d) 7.3 (a)

7.4 (a) Li,  $\text{C}_2\text{H}_5\text{NH}_2$ ,  $-78^\circ\text{C}$ , then  $\text{NH}_4\text{Cl}$   
(b)  $\text{H}_2/\text{Ni}_2\text{B}(\text{P}-2)$  or  $\text{H}_2/\text{Pd}/\text{CaCO}_3$  (Lindlar's catalyst)  
(c)  $\text{H}_2/\text{Ni}$  or  $\text{H}_2/\text{Pt}$  using at least 2 molar equivalents of  $\text{H}_2$   
(d)  $\text{C}_2\text{H}_5\text{ONa}/\text{C}_2\text{H}_5\text{OH}$   
(e)  $(\text{CH}_3)_3\text{COK}/(\text{CH}_3)_3\text{COH}$   
(f)  $\text{Zn}/\text{CH}_3\text{CO}_2\text{H}$  or  $\text{Na}/\text{acetone}$



7.6 (a)  $\text{CH}_3\text{CH}(\text{Br})\text{CH}_2\text{Br}$  (b)  $\text{CH}_3\text{C}\equiv\text{CNa}$  (c)  $\text{CH}_3\text{C}\equiv\text{CH}$   
(d)  $\text{CH}_3\text{C}\equiv\text{CNa}$  (e)  $\text{CH}_3\text{CH}_2\text{Br}$

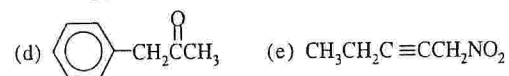
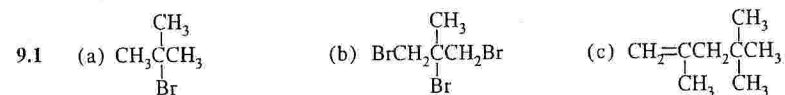


## CHAPTER 8

8.1 (e) 8.2 (c) 8.3 (e) 8.4 (a) 8.5 (d) 8.6 (c)

8.7 (e) 8.8 (b)

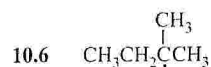
## CHAPTER 9



9.2 (c) 9.3 (a)

## CHAPTER 10

10.1 (d) 10.2 (b) 10.3 (c) 10.4 (b) 10.5 (c)

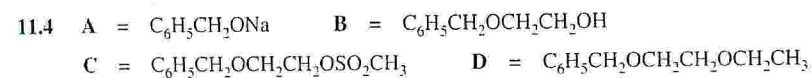


10.7 Six

10.8 (d)

## CHAPTER 11

11.1 (d) 11.2 (a) 11.3 (e)

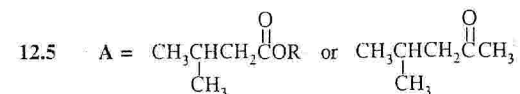
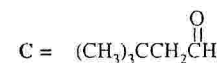
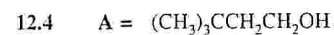


## CHAPTER 12

12.1 (b) 12.2 (a)



B = NaH

C =  $\text{CH}_3\text{I}$ 

## CHAPTER 13

13.1 (d) 13.2 (c) 13.3 (c) 13.4 (c) 13.5 (b)

## CHAPTER 14

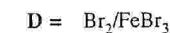
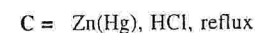
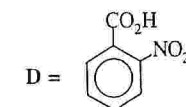
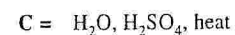
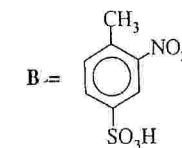
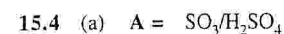
14.1 (e) 14.2 (a) 14.3 (b) 14.4 (b)



14.6 Azulene

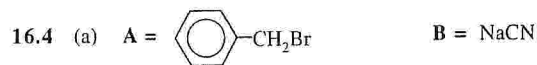
## CHAPTER 15

15.1 (a) 15.2 (a) 15.3 (b)

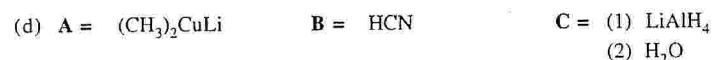
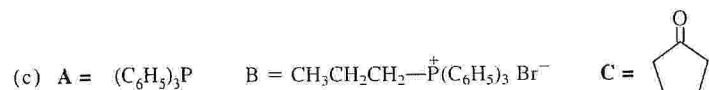
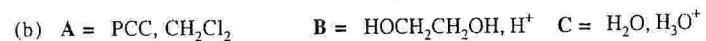


## CHAPTER 16

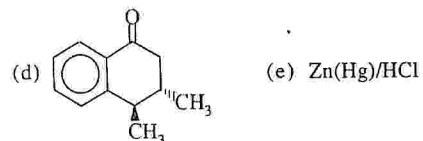
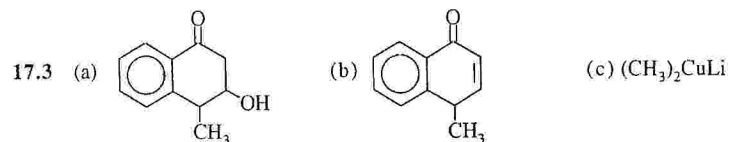
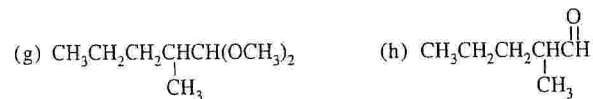
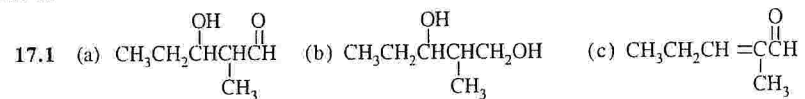
16.1 (d) 16.2 (b) 16.3 (b)



$C = (1) \text{ DIBAL-H, hexane, } -78^\circ\text{C}, (2) \text{ H}_2\text{O}$



## CHAPTER 17



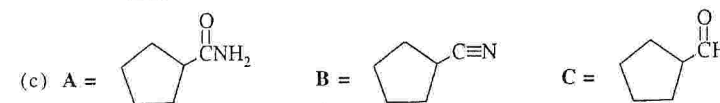
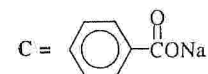
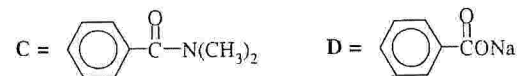
17.4 (e) 17.5 (a)

## CHAPTER 18

18.1 (b) 18.2 (d) 18.3 (d)

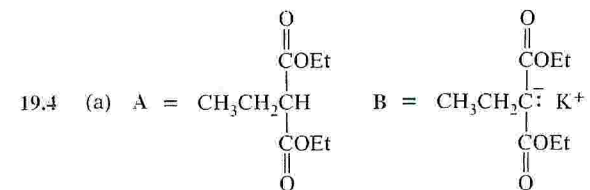
18.4  $A = 3\text{-Chlorobutanoic acid}$  $B = \text{Methyl 4-nitrobenzoate}$  $C = N\text{-Methylaniline}$ 

18.5 (a)  $A = (1) \text{ KMnO}_4, \text{OH}^-, \text{heat}$   $B = \text{SOCl}_2 \text{ or } \text{PCl}_5$   
(2)  $\text{H}_3\text{O}^+$

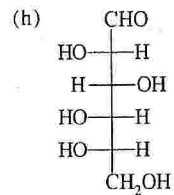
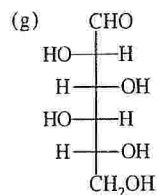


## CHAPTER 19

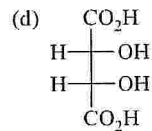
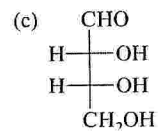
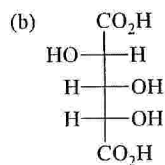
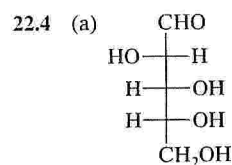
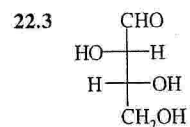
19.1 (c) 19.2 (e) 19.3 (b)



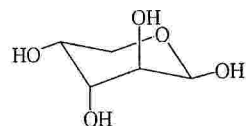




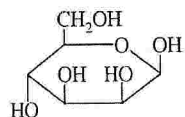
22.2 C



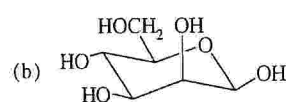
22.5



22.6 (a)



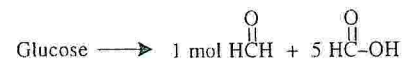
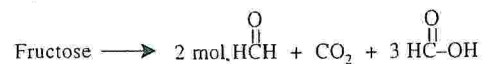
(b)



(c) Reducing

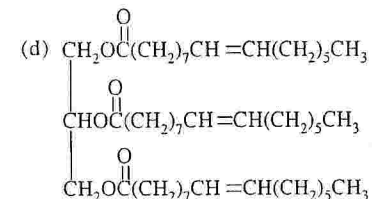
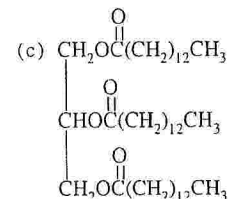
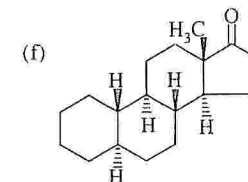
(d) Active (e) Aldonic (f) Active (g) Aldaric (h)  $\text{NaBH}_4$   
(i) Active

22.7 (a) Galactose  $\xrightarrow{\text{NaBH}_4}$  optically inactive alditol  
(b)  $\text{HIO}_4$  oxidation  $\longrightarrow$  different products:



22.8 (e) 22.9 (d)

## CHAPTER 23

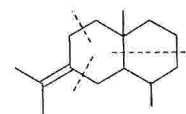
23.1 (a)  $\text{CH}_3(\text{CH}_2)_{12}\text{CO}_2\text{H}$ (b)  $\text{CH}_3(\text{CH}_2)_{12}\text{C(=O)ONa}$ (e)  $\text{CH}_3(\text{CH}_2)_{13}\text{SO}_3\text{Na}$ 

23.2 (a)  $\text{I}_2/\text{OH}^-$  (iodoform test) (b)  $\text{Br}_2/\text{CCl}_4$  (c) Ethynylestradiol only shows IR absorption at  $\sim 3300\text{ cm}^{-1}$ .

23.3 5 $\alpha$ -Androstane23.4 (a)  $\text{CH}_3(\text{CH}_2)_4\text{CH}_2\text{C}\equiv\text{CH}$  (b)  $\text{CH}_3(\text{CH}_2)_5\text{C}\equiv\text{CNa}$ (c)  $\text{CH}_3(\text{CH}_2)_5\text{C}\equiv\text{C}(\text{CH}_2)_6\text{CH}_2\text{Cl}$  (d) KCN(e)  $\text{CH}_3(\text{CH}_2)_5\text{C}\equiv\text{C}(\text{CH}_2)_7\text{CO}_2\text{H}$  (f)  $\text{H}_2/\text{Pd}$ 

23.5 Sesquiterpene

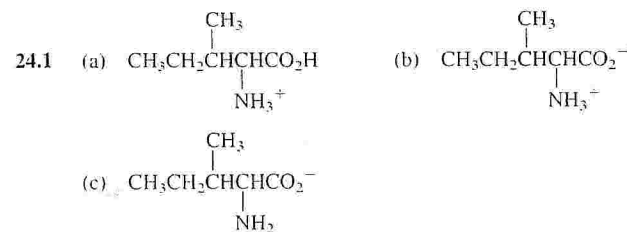
23.6



23.7 (e)



## CHAPTER 24



24.2 Pro-Leu-Gly-Phe-Gly-Tyr

## C

APPENDIX  
Molecular Model Set Exercises

The exercises in this appendix are designed to help you gain an understanding of the three-dimensional nature of molecules. You are encouraged to perform these exercises with a model set as described.

These exercises should be performed as part of the study of the chapters shown below.

| Chapter in Text | Accompanying Exercises                                   |
|-----------------|----------------------------------------------------------|
| 4               | 1, 3, 4, 5, 6, 8, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21 |
| 5               | 2, 7, 9, 13, 24, 25, 26, 27                              |
| 7               | 9, 19, 22, 28                                            |
| 2               | 31                                                       |
| 3               | 23                                                       |
| 22              | 29                                                       |
| 24              | 30                                                       |
| 12              | 31                                                       |

The following molecular model set exercises were originally developed by Ronald Starkey.

Refer to the instruction booklet that accompanies your model set for details of molecular model assembly.

## EXERCISE 1 (Chapter 4)

Assemble a molecular model of methane,  $\text{CH}_4$ . Note that the hydrogen atoms describe the apexes of a regular tetrahedron with the carbon atom at the center of the tetrahedron. Demonstrate by attempted superposition that two models of methane are identical.

Replace any one hydrogen atom on each of the two methane models with a halogen to form two molecules of  $\text{CH}_3\text{X}$ . Are the two structures identical? Does it make a difference which of the four hydrogen atoms on a methane molecular you replace? How many different configurations of  $\text{CH}_3\text{X}$  are possible?